A Study of Bird Flight

By Dr. E. H. Hankin, M.A., D.Sc.

CHAPTER I.—Introductory.

ABOUT 23 miles from Agra the rocky hill of Futtepur-Sikir rises steeply from the plain. If a wind is blowing birds may be seen gliding at their ease over the crest of the hill, apparently taking advantage of the ascending current of air. But I have also been at Futtepur-Sikri on other occasions, when the wind was so light that it was impossible to tell its direction by puffing smoke from a cigar. Then I have seen the birds, in this apparent calm, making the same astounding movements of soaring flight, sometimes gliding horizontally, sometimes—for a few feet—rising as steeply as if they were climbing some invisible staircase, but always with an absence of any visible effort and only with occasional directive movements that were as difficult to understand as to see.

If no explanation is forthcoming of a natural phenomenon, what is required is not theory but observation and measurement. I have thought it worth while, therefore, to take advantage of such opportunities as I have had by making observations and measurements on soaring flight, and on the conditions under which it occurs.

The species of birds that came under my notice, in the first instance, were the following :—

1.—The cheel (*Milvus govinda*): Span, 4 ft.; loading, ·55 lb. per sq. ft.

2.—The white scavenger vulture (*Neophron gingianus*): Span, 5 ft.; loading, ·87 lb. per sq. ft.

3.—The black vulture (*Otogyps calvus*): Span, 6½ ft.; loading, 1·23 lbs. per sq. ft.

4.—The white backed vulture (*Gyps bengalensis*), which I shall refer to as the common or large vulture. Span, 7 ft.; loading, 1·13 lbs. per sq. ft.

It will be noticed that these birds differ greatly in the amount of weight lifted per square foot of wing area. It will be seen that these differences are in close relation with their capacity for soaring flight under different conditions. The lightweight cheel is able to soar under conditions that quite exclude any attempt at soaring flight on the part of the heavier birds.

The cheel, or pariah kite, is perhaps the commonest bird in Indian towns and cantonments. If observed during the heat of the day, and especially in a varying wind, its movements at first sight appear to have nothing in common with the majestic circling flight of the larger soaring birds. The wings of the cheel appear to yield to every puff of wind, as it glides in any direction with astounding grace and facility. The tail at one moment is furled, at another expanded like a fan, and frequently shows sudden but slight movements of small duration. Slight changes in the inclination of the wings follow one another so suddenly and so often without easily visible effect on the direction of flight, that it may well appear a hopeless task to discover their nature and object.

The soaring flight of the larger birds is puzzling, not from an excess of directive movements, but from their apparent absence. Usually during the day a cluster of vultures may be seen circling over any slaughter-house in or near Agra. At the time of starting their morning flight they usually cease flapping at a height of from 10 to 20 metres from the ground. They then glide in circles with complete absence of propulsive movement, and usually reach a height of from 500 to 700 metres in the cold weather, and up to about 1,300 metres in the hotter months of the year. Under certain conditions circle after circle may be watched without any movements of the wings being seen. Their gliding, whether or not it may happen to be accompanied by gain in height, often appears as undirected as it is free of effort.

CHAPTER II.—Observations on the Time of Commencement of Soaring Flight.

From the foregoing description it will be appreciated that at the time of commencing my observations, it appeared to me that there was little hope of learning much about soaring flight by watching the movements of the birds when they had reached a great height. Obviously at any given moment a bird may be trying to gain height, to remain where it is, or to descend. When, on the other hand, the birds are near the ground and commencing to soar, there is more probability that at any given moment they are trying to rise. From this point of view it occurred to me that it was worth while to observe soaring birds as they started in the early morning.

My observations soon revealed the unexpected fact that there is a definite time, varying from day to day, at which soaring commences. For instance, if on a particular day in October I saw a cheel soaring for the first time at 8.30 a.m. then within a few minutes at least a dozen cheels would be seen circling in the air. My post of observation was on the roof of my house, from which position I have a view of several square miles of country, including the town and cantonment of Agra. Apparently within, as a rule, about five minutes the air becomes capable of supporting soaring flight over the whole area observed.

When the fact is thus baldly stated another possibility suggests itself, namely, that cheels have an instinct that teaches them not to indulge in soaring flight before half-past eight. A closer acquaintance with the facts definitely excludes this possibility. For instance, at Jharna Nullah, near Agra, is a factory of dried buffalo flesh. If in the early morning a gun is fired near this factory, cheels and vultures rise in flap-gliding flight, and in a minute or two, settle. I may parenthetically explain that soaring birds never indulge in prolonged flapping flight. Flapping is always alternated with periods of gliding; each period may last for a few seconds. I propose to describe this form of flight as "flap-gliding." Supposing a gun is fired a little later, when the air has become soarable for cheels, but not for vultures, they (the cheels, that were still settled) will rise into the air and remain there circling. Usually about half an hour to an hour later the air has become soarable for vultures. On then firing a gun, any vultures that had not yet started will rise into the air and circle. As will be further described in a later chapter, the different species of soaring birds start at somewhat definite times after the cheel. The heavier the bird, the later is this time. Further, I shall have to describe different forms of soaring flight, and shall show that they commence at different times after the commencement of circling. These different facts taken together leave no room for doubt that the air in the early morning is unsuitable for soaring flight, and that in fine weather it gets more and more suitable for such flight as the day goes on.

I propose to bring forward evidence bearing on the question of the nature of the change in the air that makes it soarable in a later chapter. But I may state here that my observations make it practically certain that this change has nothing directly to do with any strengthening of the force of the wind. Soaring often commences at a time when the early morning wind has just died away, and when such wind as exists is so light that it is difficult to determine its direction.

As illustrating the facts under discussion I will here bring forward an extract from my diary :—

November 25th, 1909.—From 8.30 onwards the wind was light, and unable to move the leaves of the trees near, but at 9.35 the leaves were occasionally in motion.

8.44 to 9.16.—Fifteen cheels were observed at intervals either flap-gliding or flap-circling.

9.17.—Two cheels circling, and two flap-circling near house.

9.18.—Two cheels circling near infantry barracks, 1½ miles distant.

9.19.—One cheel circling near Company Garden (1 mile distant) and one circling near fort (1¾ miles distant).

9.35.—Many cheels circling in different directions.

The time of commencement of circling of cheels is usually at about 9.30 during December. The time gets earlier month by month as the weather gets warmer, till in June cheels are able to circle usually by 7 a.m. From June onwards the time gradually recedes.

CHAPTER III.—Description of Circling Flight.

In the following description of circling I shall make use of two expressions that will be familiar to yachtsmen: by "up-wind" I mean a direction against the wind or going to windward; by the term "down-wind" I mean a direction with the wind or going to leeward. I use the term "circle" and "circling" as a matter of convenience, although, as will be shown later, the tracks described by circling birds are not perfect circles.

At the commencement of circling flight in the morning the cheel shows the same steady and, so to speak, careful flight as do the heavier birds later in the day. The wings appear to remain in the same plane, and the use of balancing or directive movements can only with difficulty be discovered.

The cheel rises into the air by flapping flight to a height of a few feet above the tree tops. Then it commences to glide in circles. Sometimes at first these circles are described partly by gliding and partly by flapping. The flapping usually occurs on the up-wind side of the circle. But, either immediately or after a short interval, the bird will be seen to be circling without flapping. In spite of the absence of propulsive effort the bird will be seen to be gaining height. The gain of height is usually on the up-wind or windward sides of the track.

In the case of vultures, at the commencement of their circling flapping may occur at any part of the circle. In one circle there may be four of five periods of flapping. But when the flapping ceases the gain in height will, as a rule, be seen, as in the case of cheels, to be mainly on the up-wind and windward sides of the circle.

This gain in height on the windward and up-wind parts of the circle is the more surprising, in that the cheel all the time is drifting to leeward. Each circle described is a few feet to leeward of its predecessor. More than once, when the wind was light and variable, I have discovered a change in its direction by observing the position of gain of height of a circling cheel, and proved the truth of the information thus obtained by seeing the direction of some smoke. Captain S. Hutcheson, of the 3rd Brahmans, informs me that he has made the same observation of gain in height while going to windward in soaring birds, both in South Africa and in the Himalayas.

But this windward gain of height is not a constant phenomenon. Sometimes there is a gain of height on the leeward side of the circle; sometimes height is gained on the down-wind side. Rarely gain in height appears to occur almost equally all round the circle.

The following extract from my diary is an example of leeward gain of height:—

December 24th, 1909.—In the morning the sky was clouded over. There was a light east wind. The sun came out at 10.30, and soaring commenced at 10.35. At 1.30 I was standing on the top of the gateway of the mosque at Futtepur-Sikri. The sun was shining. The wind was from the east and very light; its direction was shown by smoke from a fire on the top of the ridge below me. The column of smoke was inclined over towards the west, and showed slow but distinct movement. Also occasionally I could feel the movement of the air. Some cheels, a white scavenger vulture and a large vulture were soaring at a lower level than where I was standing at about 100 yards distance. The vulture was seen to gain height both at the windward and at the leeward sides of the circle.

Certainly sometimes, perhaps always, when there is gain of height on both the windward and leeward sides, there may be a loss of height between the two positions of gain, that is to say, during the up-wind and down-wind parts of the circle. For instance, in the case of a vulture circling overhead in the afternoon, with a westerly wind, I have observed that the sun illuminated the under sides of the wings at the commencement of the down-wind side of the track, proving that at that moment the bird was gliding downwards.

A noteworthy fact about the early morning circling of cheels and the circling of other birds later in the day is its slowness and regularity. Whenever I have had an opportunity of measuring the size of circles described by cheels I have found them to be about 12 metres in diameter. The circles described by vultures are generally about 40 or 50 metres in diameter.

Cheels take 7 to 9 seconds, as a rule, to complete a circle. If a succession of circles are timed with a stop watch, the period in the case of cheels often will be found not to vary by more than one-fifth of a second. The larger birds usually circle in from 13 to 16 seconds.

The following extracts from my diary may be quoted in support of the above statements:—

October 31st, 1909.—On Tundla Road to leeward of Jharna Nullah. Wind west. A white scavenger vulture observed to make successive circles in 9, 8, 10, 9, 10 and 12 seconds. Then it made a circle of 7 seconds and glided off in a straight line. A large vulture about 150 metres overhead made successive circles in 19, 10, 13, 15, 13 and 13 seconds. An eagle circled in 11, 14 and 15 seconds. A black vulture made successive circles in 17, 16, 15 and 20 seconds. While making these observations a feather was seen floating in the air at 10.20 and three feathers at 10.30. They were at the height at which the birds were soaring. They drifted at about walking pace and appeared to travel horizontally.

December 30th, 1909, at Jharna Nullah.

9.45.—Cheels began circling.

9.53.—White scavengers began circling with occasional flaps. They circled in 12 seconds. Cheels were circling in 9 seconds usually, but sometimes in 10 or 11 seconds. (My observations suggest that the rate is usually less in warmer weather.)

9.55.—Five columns of cheels were up.

10.22.—White scavengers circling without flapping.

10.24.—Large vultures had commenced soaring and were circling in 13 seconds.

10.35.—A feather seen floating in the midst of a group of circling cheels. It was about 10 metres above my head. Observation with the telemeter failed to show either rise or fall. At this time cheels were circling in 11 seconds, and vultures in 13 to 16 seconds.

10.45.—First black vulture seen soaring.

11.15.—A black vulture seen making circles in 15 seconds.

In another kind of soaring flight about to be described the speed is distinctly faster than it is in circling. If soaring is difficult and if the bird has to flap for part of the circle, the speed is, so far as I have observed, the same as it would be if the bird were gliding the whole way round. There is no attempt to increase speed in order to make gain in height easier. In my notes I find the suggestion that perhaps the air has a structure in virtue of which the soaring bird can only take energy from it at a particular speed, which speed may be different under different conditions. Evidence that I hope to bring forward in a later chapter will, I think, show that this suggestion only partially represents the actual facts of the case.

Apart from the gain in height, which does not necessarily occur in every circle, the circles described by soaring birds are practically always perfectly horizontal.

In a later chapter I hope to describe my observations on directive movements in gliding flight. It will then be possible to describe the movements of the circling bird in greater detail, but, as will be seen, without in this way arriving at any solution of the mystery.

(To be continued.)

Grahame-White is Returning to America.

CONSIDERING how successful was Mr. Grahame-White's tour in America last autumn, it is not surprising to hear that he has arranged to visit the States again. He leaves to-day (Saturday) on the "Mauretania," *en route* for New York.

No doubt he has designs on some of the speed prizes, as in addition to a 50-h.p. Grahame-White Baby biplane, he is taking over with him a two-seater Nieuport monoplane, engined with a 70-h.p. Gnome. He will, however, find a serious rival in Weymann, who has crossed the Atlantic with his Gordon-Bennett-winning 100-h.p. Gnome-Nieuport, and who evidently has similar designs on speed prizes. Nevertheless, he should make a good thing out of passenger-carrying, as, up to the present, the American enthusiasts have had no option but to take their aerial excursions in biplanes. In fact, as far as memory can be trusted, Sopwith's 70-h.p. two-seater Blériot seems to be the only passenger-carrying aeroplane that has yet visited the States, and this machine unfortunately suffered disintegration soon after its arrival.

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CHAPTER IV.—Graphic Records of the Track of Soaring Birds.

THE observations recorded in the preceding chapters suggest that soaring flight is not due to the bird being able to take advantage of chance currents of air. Any attempt to explain soaring flight on the basis of the description hitherto given would be premature. It is necessary, firstly, to consider in greater detail evidence bearing on the question whether or not wind is of importance for soaring. This I propose to do in a later chapter. Secondly, it is necessary to get more definite evidence as to what are the actual movements in soaring flight. For this purpose records of the track of soaring birds will be of help.

It occurred to me that if I watched the image of a circling bird in a looking-glass (with one eye closed) I could obtain a record of the track by following the image of the bird with a pen. Obviously, too, more information would be obtained if, instead of making a continuous line, the pen was used to make dots at regular intervals of time. To obtain the intervals I used a metronome set to tick either at half-second or 1 second intervals. For the pen I used a stylograph containing copying ink suitably diluted. After the record has been made a piece of paper is placed on the looking-glass and rubbed. Thereby a permanent copy of the record is obtained.

Fig. 1 is a looking-glass record of the track of a circling cheel marked at ½ second intervals. At the time this record was made the wind was very light, scarcely enough to move leaves. Hence the bird shows but little leeward drift, and the successive circles overlap closely. The time marks may be seen to be closer together on the windward side than they are on the leeward side of each circle. This means that the bird was travelling more slowly on the windward side of the track. There can be little doubt that this loss of speed is connected with gain of height, which, as already explained, usually occurs on the windward side of the circle. In this illustration, as in succeeding ones, the large arrow indicates the direction of the wind. The small arrow shows the direction of flight of the bird.

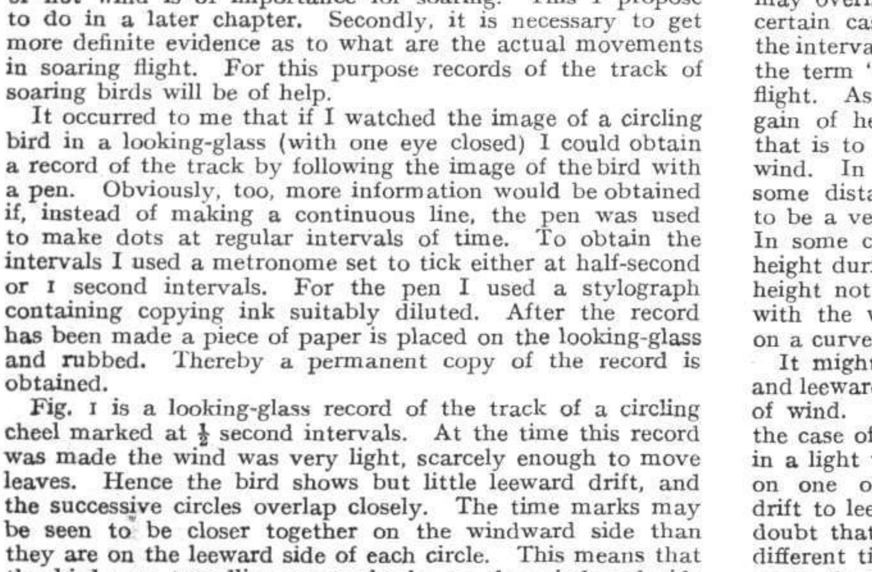

Fig. 1—January 8th, 1911. Jharna Nullah. Track of cheel circling marked at ½-second intervals. Note lessened speed on windward side of track. Fig. 2.—Track of cheel circling. Fig. 3.—Track of cheel circling in light wind. Fig. 4.—January 10th.—Jharna Nullah. Vulture leeward looping in a strong wind. Fig. 5.—January 8th, 1911. Jharna Nullah. Scavenger leeward-looping. This was the first scavenger seen up. Cloud was getting thinner, and soarability was increasing. Previously cheels only had been circling. Note diminution of speed all round the loop. Track marked at ½-second intervals.

More usually the circles overlap by a greater distance, as shown in Fig. 2. In this case there is very little difference between the speeds shown on the leeward and windward sides of the circle. It is probable that it is a case of "ease-circling," that is to say, circling without attempt to gain height. The wind was very light, just enough to move leaves, when this record was taken.

In the presence of a certain amount of wind the circles may overlap by a greater distance, as shown in Fig. 3. In certain cases, especially in the presence of a strong wind, the intervals between the loops may be still greater. I propose the term "leeward looping" to describe this latter form of flight. As shown in Fig. 4, the diminution of speed indicating gain of height may occur chiefly at the point marked A, that is to say, when the bird has turned round to face the wind. In some cases in leeward looping, when observed at some distance from the side, there appears at this point to be a vertical gain of height of as much as 1 or 2 metres. In some cases in leeward looping the bird appears to gain height during the whole of the loop. That is to say, it gains height not only while facing the wind, but also when going with the wind—in short, during the whole time that it is on a curved course. Such a case is illustrated in Fig. 5.

It might be thought that the difference between circling and leeward looping depends merely on the presence or absence of wind. I doubt whether this is the case. For instance, the case of leeward looping illustrated in Fig. 5 was recorded in a light wind just strong enough to move leaves. I have on one occasion seen circling with scarcely perceptible drift to leeward in a strong, stormy wind. There can be no doubt that the amount of leeward drift in circling differs at different times, owing to factors not yet understood. I may quote the following diary extracts bearing on this matter:—

July 14th, 1910. At 6.46 two cheels seen circling together. One changed its movement from circling to leeward looping. Shortly afterwards the other made a similar change. A minute later both birds glided down and settled. Widespread soaring began at 7.14.

September 29th, 1910. At 3.35 an east wind, somewhat strong, moving branches. Sunshine. Isolated small cumulus clouds. Scanty clouds of higher layer. Four vultures seen circling in and out of the base of a small cumulus cloud at a height of 1,100 metres. Their leeward drift was not so much as that of the cloud. In a few minutes they were circling nearly overhead, and the cloud was far away to leeward. I made no record of the size of this cloud, but my recollection is that it was not larger in any dimension than eight or ten times the span of a vulture. Cheels and vultures were circling and flex-gliding to windward. They were leeward looping when going to leeward.

Referring to Fig. 5, it will be noticed that there is a somewhat sudden increase of speed immediately after the loop and at the commencement of the leeward glide. I have been able to observe the adjustment of the wings used to initiate this increase of speed, and shall describe it in a later chapter. The length of the leeward glide may, in some cases, amount to 100 metres or more.

CHAPTER V.—Flex-gliding.

On first beginning the study of soaring flight, I was puzzled by the apparently large number of species of birds that were to be seen. In particular there was a large vulture the under side of whose wings appeared white or yellow in front, and black along the posterior margin. It carried its wings advanced so that the wing-tips were on a level with the beak. Another bird had the same colouring,

but carried the anterior margin of its wings in a perfectly straight line with one another. Yet a third species was similar in colouring but had the wings somewhat flexed with the wing-tip feathers pointing outwards and backwards. It was only after some acquaintance with the subject that I discovered that these different birds were all of one species, namely, the common large vulture, but with their wings in different positions according to the kind of flight in which they were indulging.

If a circling vulture is watched its wings will be seen to be in the dihedrally up position. The amount of the dihedral angle varies under different circumstances as will be described in a later chapter. The wings also are fully extended, and if the air is fully soarable they are somewhat advanced, so that their tips lie on a level with the beak. Sooner or later a change in the mode of flight will be noticed. The bird is no longer canted over, as is always the case in circling, but is seen to be gliding in a straight line and on a level keel. While thus gliding the wings are no longer fully extended

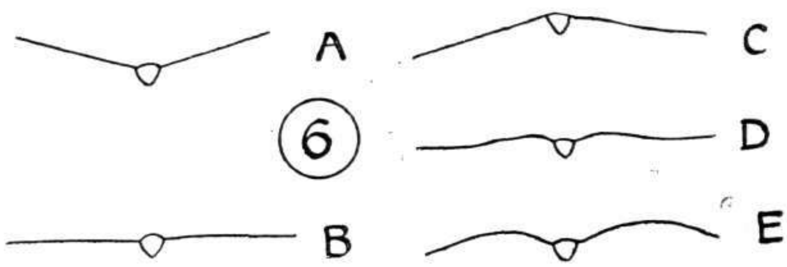

Fig. 6.—Diagrammatic end on view of birds with wings in different positions. A, wings dihedrally up. B, wings flat. C, wings dihedrally down. D, appearance presented by cheels when flex-gliding. E, wings arched.

but are more or less flexed. For this reason I propose the term "flex-gliding" for this form of flight. The speed can be seen to be greater than it is in circling, and the more the wing is flexed, that is to say, the more the span of the bird is diminished the greater is the speed. In Fig. 7 is shown the outline of a cheel when circling. In this bird, advancing of the wings when circling is not well marked. In Fig. 8 the cheel is shown with wings slightly flexed as seen in flex-gliding at low speed. In Fig. 9 the outline is shown with wings strongly flexed as occurs in fast flex-gliding. When seen from behind and from a distance the flex-gliding cheel has the appearance shown in Fig. 6 D. That is to say the inner portion of the wing appears to be curved upwards. For a long time the meaning of this appearance was unknown to me. In a later chapter I hope to describe the fortunate chance that led me to discover the meaning and nature of this adjustment.

In flex-gliding there is no dihedrally-up angle; the wings are perfectly flat, but as will be shown later the centre of gravity is still at a lower level than the centre of lifting effort of the wings.

In attempting to discover the source of energy of soaring flight it obviously is desirable that measurements should be made both of the height at which birds soar, that is to say of the height they may obtain without flapping, and also of the speed at which they travel.

To measure the height of soaring birds I have made use of the "Souchier telemetre." This instrument is a binocular field glass with an arrangement by means of which a crystal of Iceland spar can be placed over each eyepiece. When the Iceland spar is in position the image of the object looked at is seen double. The further away the object the further apart do the two images appear. Hence, if the size of the object is known an estimate can be made of its distance. In my instrument the overlap of the two images for 100 metres is five inches. If the object is 200 metres away the overlap is ten inches. For instance, if on looking at a bird whose wings are known to me to be ten inches wide, the images of the wings are seen to be just clear of one another the distance of the bird is at once known to be 200 metres. Nearly every specimen of the common vulture I have shot was found to be of 84 or 85 inches span. Supposing a vulture at a height is looked at with the telemetre. If the two images exactly overlap so that the wing-tip of one image touches the wing tip of the other image, then since $85 = 17 \times 5$, the distance of the bird must be 1,700 metres. I have on one or two occasions seen vultures circling at this immense height.

I have made what I believe to be a new application of the telemetre, namely in using it to measure the speed of gliding flight. I found by measurement that at a hundred metres distance the width of its field of view is six metres. At 200 metres the width of the field of view was found to be 12 metres, at 300 metres it was found to be 18 metres, and so on. Consequently the speed of the bird can be estimated by measuring, with a stop-watch, the time of its passage across the field of view. For instance, suppose the distance of a flex-gliding vulture has been found to be 600 metres. Its time for crossing the field of view when the telemetre is held steady is found to be two seconds. Then the width of the field of view at 600 metres distance is known to be 6×6, that is to say 36 metres. Therefore the bird travels 36 metres in two seconds. Therefore its speed is 18 metres per second.

I propose to give a somewhat lengthy series of extracts from my diary giving examples of measurements of speeds by this method. There is a prevalent opinion that soaring consists in the bird being able to take advantage of chance currents of air. The speeds of soaring flight actually measured give scant support to this view. In the early morning before soarability is fully established, flex-gliding takes place with loss of height. But a few minutes later the direction of flex-gliding may be seen to be apparently horizontal. It seems scarcely likely that there is any loss of height that can account for speeds of 20 metres per second, which may be continued over distances of several miles. Such facts suggest that the soaring bird has at its disposal some source of energy whose nature does not seem to be suspected. The speeds actually given for flex-gliding show an apparent variation. The disposition of the wings corresponding to each different speed will be described on a later occasion. The measurements of speeds of circling were carried out before I had in my possession the graphic method of recording the track. At the time of making these observations I had with some difficulty been able to observe a loss of speed on the up-wind side of the track. On referring to the previously given illustrations it will be apparent that greater contrasts in speed would have been obtained if I had measured the speeds on the windward and leeward sides rather than those on the up-wind and down-wind sides of the track. The following are the extracts :—

January 19th, 1910.—At 4.0.—A vulture seen flex-gliding to leeward, 300 metres up at 9 metres per second.

January 21st, 1910.—At 3.45.—A vulture circling. On the up-wind side at 5 metres per second. On the down-wind side at 9 metres per second.

January 24th, 1910.—At 10.45.—Vulture circling. Speed, down-wind side 12 and 12 metres per second. On up-wind side $8\frac{1}{2}$ and 7 metres per second.

February 3rd, 1910.—At 3.40.—Black vulture flex-gliding up wind at 500 metres height at 15 metres per second. Another black vulture at same height flex-gliding with wind on beam at 20 metres per second. Vulture at 400 metres height flex-gliding up wind at 8 metres per second. Cheel at 800 metres beam on flex-gliding at 12 metres per second.

4.0 —Vulture at 200 metres height circling. Speed up-wind 3 metres, and down-wind at 12 metres per second. Vulture at 500 metres flex-gliding down-wind at 20 metres per second.

February 9th, 1910.—At 4.35.—A vulture circling at 100 metres up exactly overhead. Its speed on up-wind side was 6 metres and on down-wind side 12 metres per second. A vulture at 250 metres height flex-gliding up-wind at 21 metres per second.

February 14th, 1910.—At 3.52.—Black vulture seen flex-gliding up-wind at 700 metres height at 20 metres per second.

At 3.54.—A vulture seen at 1,700 metres height flex-gliding. It was visible only for a second or two by the naked eye.

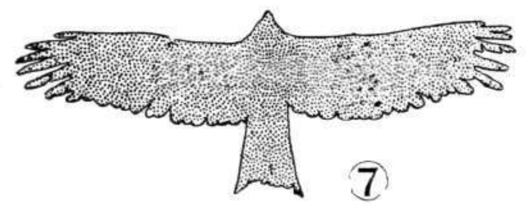

Fig. 7.—Outline of a cheel when circling.

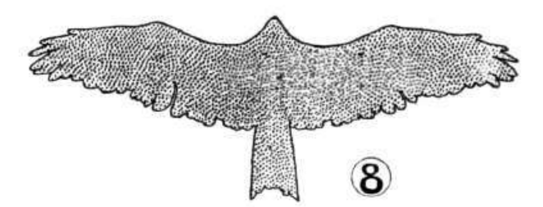

Fig. 8.—Outline of a cheel when slow flex-gliding.

Fig. 9.—Outline of a cheel when fast flex-gliding.

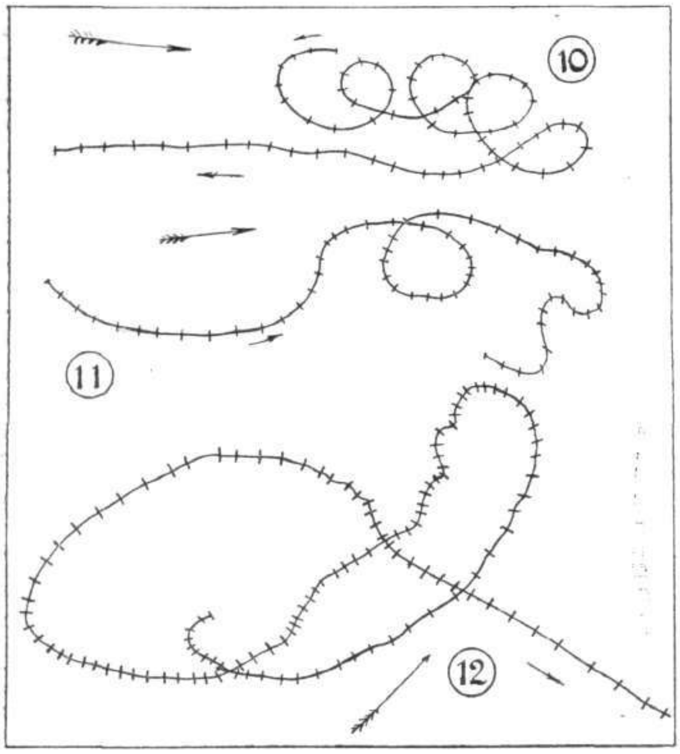

Fig. 10.—January 8th, 1911. Jharna Nullah. Cheel circling and then flex-gliding up wind at slow rate. At the time there was thin cloud, and no fast flex-gliding had occurred. A few minutes later, as cloud got thinner, fast flex-gliding of cheels began. Track marked at 1-second intervals. Wind at the time not strong enough to move leaves. Fig. 11.—January 8th, 1911. Jharna Nullah. Cheel ease-gliding and making one circle. Track marked at ½-second intervals. Fig. 12. — January 10th. Jharna Nullah. Vulture ease-gliding, and then flex-gliding in a strong wind.

At 4.0.—Cheel at 1,200 metres height flex-gliding up-wind at 9 and 10 metres per second.

February 19th, 1910.—At 9.46.—A vulture flap-gliding up-wind at 18 metres per second. At 9.47.—This vulture was circling. Speed on up-wind side 7 metres, on down-wind side 12 metres.

February 20th, 1910.—At 10.7.—Four vultures seen circling at 400 metres height. At 10.10.—They were found to be circling at 8 metres per second both on the up-wind and down-wind sides of the circle. That is to say supposing the wind was west. But smoke from the Cantonment Railway Station appeared to be rising vertically. Leaves were quite still. Two measurements taken, after which the vultures flex-glided to north out of sight.

At 10.21.—A vulture observed at 800 metres height. It was circling at 12 metres per second both on up-wind and down-wind sides of track on the supposition that the wind was north or south. After two measurements had been made it flex-glided to north at 16 metres per second. Shortly afterwards a light draught of air came from the east, that is to say, the direction of the wind was doubtful at the time of the observations. Leaves were still and smoke was ascending vertically.

March 3rd, 1910.—At 11.30.—A strong north-west wind. Vultures circling on down-wind side showed speeds of 24, 21, 27, and 27 metres per second. On the up-wind side speeds were measured of 7, 7½, 9, 9 and 9 metres per second. (The wide difference of speeds measured on up- and down-wind sides must have been due to the unusually strong wind.)

October 11th, 1910.—At 4.35.—Vultures circling at 1,200 metres. Wind west, leaves still.

November 12th, 1910.—At 3.33.—A vulture seen fast flex-gliding in and out of the base of a cumulus cloud at 1,700 metres height.

Flex-gliding can take place in any direction relative to the wind. I have, however, only observed flex-gliding direct to leeward in very light and in irregular puffy winds. In a strong and steady wind birds usually go to leeward by leeward-looping.

(To be continued.)

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A New Spanish Military School.

THE Spanish military authorities have decided to establish a flying school close to Carabauchel. Louis Dufour has been appointed instructor, and the pupils include three captains and two lieutenants.

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Mdlle. Marvingt, the winner of the Coupe Femina for lady aviators, who last week, owing to motor trouble, descended in a skittle-alley whilst flying near St. Etienne, is not only a flyer of distinction, but is an all-round sportswoman. Skiing is amongst her favourite pastimes, and above she is seen in the centre at Chamonix during the enjoyment of this exhilarating sport.

A Study of Bird Flight

By Dr. E. H. Hankin, M.A. DSc.

CHAPTER VI.—Ease-Gliding and Lift-Gliding.

ON any fine day, after soarability has been established, a large number of birds of different species may be seen circling and gliding over the Jharna Nullah factory. At intervals a cluster of birds becomes separate from the rest and commences to drift, circling more or less directly to leeward. Sometimes as many as half a dozen clusters each containing one or two hundred birds may be seen at one time. Sometimes I have been able to observe that the starting of a cluster of birds to leeward was coincident with the coming of a puff of wind. After the cluster has drifted one to three miles to leeward it breaks up and the birds that had formed it may be seen flex-gliding either directly up-wind to join the original group of birds over the slaughter-house, or else they flex-glide in different directions to join other groups of circling birds. In a light wind the birds may be seen to be flex-gliding at low speed with wings only slightly flexed. If the wind freshens all the birds in sight may be seen suddenly to increase the flexing of their wings, that is to say to make the adjustment necessary for flex-gliding at higher speed. Fig. 10 is a looking-glass record of the track of a cheel first circling and drifting with the wind, and then flex-gliding up-wind at slow speed.

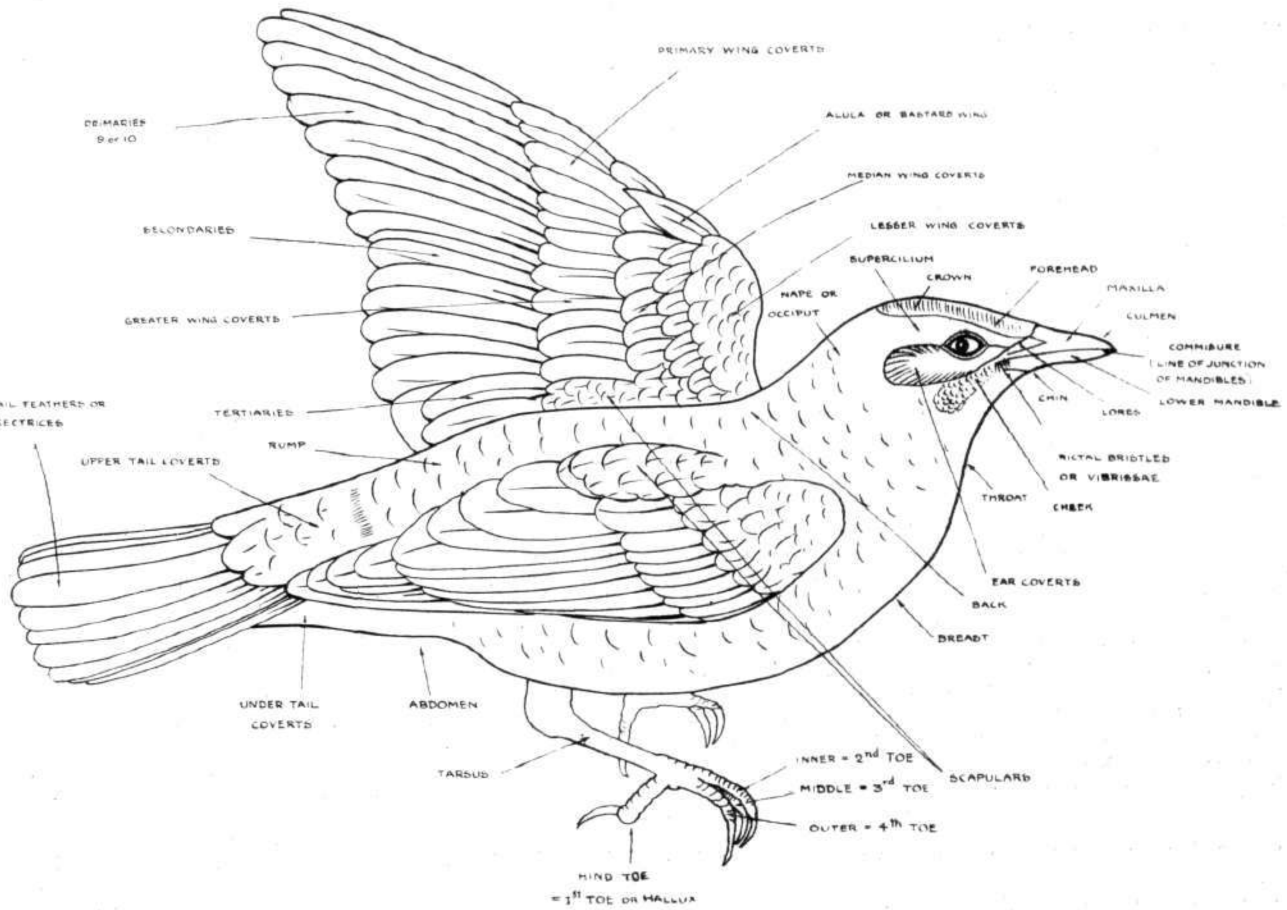
Some time after morning soarability for cheels has been established these birds may often be seen gliding in irregular curves without gain or loss of height and at moderate speed. I propose the term "ease-gliding" for this form of flight. Scavengers also indulge frequently in ease-gliding. The heavier vultures show this form of flight less often. Fig. 11 shows the track of a cheel while ease-gliding. Ease-gliding of a vulture is shown in Fig. 12.

In the case of vultures when ease-gliding, the wings are held flat and the front margins of the two wings are in one straight line, that is to say, there is no dihedrally-up angle and the wings are not advanced.

In rare cases cheels and vultures may be seen gliding up-wind in a more or less straight line with gain of height. For this form of flight I propose the term "lift-gliding." In lift-gliding the wings are held in the same position as in circling. In lift-gliding the bird always shows instability round the dorso-ventral axis. By this term I mean the axis that is vertical if the bird is gliding horizontally. In this kind of instability the bird shows a tendency to rotate for short distances to and fro round the axis in question.

The distance through which a bird may lift-glide varies from a few metres up to one or two hundred metres. At the end of a lift-glide the bird may either begin circling, or, flexing its wings, may flex-glide up-wind at increased speed. In either case its previous instability at once vanishes. I shall have occasion to describe lift-gliding more minutely after bringing forward evidence bearing on the question of the nature of soarability.

In the presence of a strong wind, currents of air are deflected upwards from the walls of high buildings. If the air is soarable cheels appear to avoid, rather than otherwise, such ascending currents. But, in the morning, before soarability has been established, and late in the afternoon, when soarability near the earth decreases, cheels collect on the windward side of such buildings and by taking advantage of the ascending currents remain ease-gliding in the air. I propose to describe this phenomenon in detail on a later occasion.



The above diagram is from "Fauna of British India Birds," by Oates and Blanford, as copied in the Journal of the Bombay Natural History Society, Vol. XVII, p. 850. As an index drawing, showing the positions of the principal parts of a bird, it should be of general interest and of particular assistance to those reading this article.

CHAPTER VII.—Canted Flex-Gliding.

I have now to describe a very remarkable phenomenon which at once shows that the problem of the nature of soarability must be solved by serious research and not by idle theorising.

As a rule a bird when flex-gliding travels on a level keel. But, during the cold weather of 1909–1910, I noticed that the heavier birds when flex-gliding in a direction at right angles to the wind appeared to be canted over away from the wind, as shown in Fig. 13, although their course appeared to be a perfectly straight line. At first I thought that the appearance was illusory. It was conceivable that in order to allow for drift the bird might not head in the direction towards which it wanted to go but towards some point to windward of this direction. But at last I noticed that such "heading" only occurs when the wind was strong, whereas canted flex-gliding was only observed when the wind was light. During January, 1910, it often happened that two or three vultures at a time could be observed flex-gliding beam on to the wind in a canted position. The following extracts from my diary illustrate my observations on canted flex-gliding:—

March 4th, 1910.—At 1.30.—A large group of vultures came towards me flex-gliding up-wind. The wind was west and very light, slightly moving leaves. When near me the vultures turned

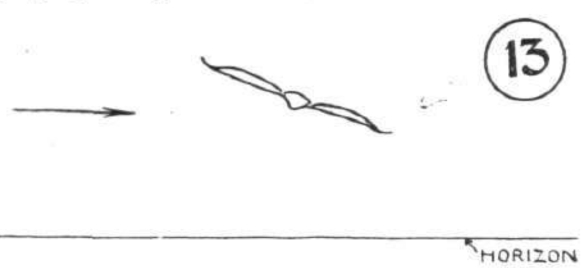


Fig. 13.—End-on view of a vulture flex-gliding in a straight line, but in a canted position, and travelling in a direction at right angles to the direction of the wind.

to the north. In doing so they became canted over away from the wind and remained thus canted over while gliding away in a straight line till out of sight. They were at different heights. One or two were quite low down, perhaps from 100 to 150 metres up.

March 16th, 1910.—At 4.16.—Some thin cloud but no cloud shadows. Blue sky overhead. Wind light and moving leaves. Several vultures showed canting.

March 27th, 1910.—At 5.20.—A vulture seen to the north, probably about a mile distant and 500 metres up. It was flex-gliding beam on to the wind, which was west. It was canted. It passed overhead showing absence of heading. When it had passed over me towards the south, it was still seen to be canted. After proceeding south for about a mile and a half, it got on to an even keel for a few seconds, then turned to the east and began circling. The wind was light, only slightly moving leaves. Factory chimney smoke was rising high.

The first entry in my diary relating to canted flex-gliding is dated November 19th, 1909. It was only in March, 1910, that I convinced myself of the reality of the appearance. The extraordinary part of the matter is that whereas during the cold weather of 1909–1910 canted flex-gliding must have been of common occurrence, from March, 1910, it has only occurred on very rare occasions. After March 27th I did not see canted flex-gliding again for four months. The observations were as follows:—

July 28th, 1910.—At 4.0.—Clouded over. Wind north, puffy, and moving branches. Circling vultures showed rapid drift to leeward. A group of five was noticed, after circling, to flex-glide off with the wind on their beam. All showed canting. A few minutes later two other vultures were seen flex-gliding in a canted position.

August 2nd, 1910.—At 4.20 to 4.30.—Two vultures seen flex-gliding to leeward and 8 vultures canted flex-gliding beam on to wind. The wind was then puffy, moving smaller branches during puffs.

August 14th, 1910.—At Futteypur-Sikri. 4.1.—Lull in wind, previously it had been moving branches and now only leaves. Low level flapping noticed (a sign of afternoon decrease of soarability near the earth). Strong sunshine.

4.10.—Four vultures seen canted flex-gliding to N.W. They were at about 800 metres height. Wind S.W. and puffy.

August 20th, 1910.—At 5.0.—Three vultures seen canted beam on flex-gliding. After about 45 seconds they got level and turned gliding to north.

The above observations in July and August had been made during the monsoon season. Canted flex-gliding was not again observed till cold weather conditions had been established. These observations were as follows:—

October 18th, 1910.—At 4.30.—A large number of vultures and one adjutant circling. Much canted flex-gliding was seen. At one moment I counted 41 vultures in canted flex-gliding. They were all canted over to the same amount. One that was fast flex-gliding was canted to the same degree as the others. The wind was west and very light, leaves being generally still.

October 21st, 1910.—At 5.0.—Group of cranes seen at about 300 metres height canted flex-gliding with occasional flapping.

Since this latter date to time of writing (February 20th, 1911), I have only seen one more case of undoubted flex-gliding in the canted position as follows:—

January 16th, 1911.—At 3.15.—A vulture seen canted flex-gliding to north. (The wind was west.)

3.17.—A vulture coming up towards me beam on to the wind was canted. It was 400 metres up and travelling at 18 metres per second. When overhead it was seen to be going straight (that is to say absence of "heading"). When it had passed over it was again seen to be canted. Near it was a scavenger vulture also canted.

3.25.—A vulture canted flex-gliding for a short distance.

3.33.—A vulture and a brown vulture going to the north canted.

3.34.—A scavenger seen fast canted flex gliding to north.

3.36.—A vulture at 300 metres height canted flex-gliding. Vultures circling at the time had wings only very slightly advanced. (Observations began at 3.15 and now discontinued.)

Almost every day during the present cold weather I have seen vultures flex-gliding in a direction at right angles to the wind but on a level keel. Despite careful observation canted beam-on flex-gliding has not been observed except in the cases above mentioned.

Cheels when flex-gliding in an ascending current of air over the battlements of the Agra fort always keep on a level keel. Hence it is difficult to see how any speculations about ascending currents of air can help us to understand the nature of canted flex-gliding.

I am acquainted with various dispositions of wings or modes of flight that occur at one time of the day and not at another, or at one season of the year and not at others. With our present knowledge it is not impossible to suggest explanations of such changes. But a mode of flight that occurs commonly in one year and rarely in another indicates the concurrence of meteorological factors whose nature is at present completely unknown.

CHAPTER VIII.—Preliminary Description of Steering Movements in Gliding Flight.

On rare occasions I have seen a species of crane circling in company with the more common soaring birds. This crane, when soaring, carries its head and neck outstretched in front and its legs stretched out behind, so that the distance from head to foot is nearly as great as the total span of its wings. With vultures, on the other hand, neither the head or tail form conspicuous objects during soaring flight. Vultures soar with their long necks coiled in such a way that the head scarcely projects beyond the line of the front of the wings. The tail is small in proportion to the area of the wings. In a vulture that I measured having a span of 82 inches the tail was 8 inches long and 4 inches wide when furled.

In cranes, adjutants, and similar birds in which the head extends for a distance beyond the line of the front edge of the wings, the head is kept perfectly still, except occasionally during descent. There is no reason for suspecting that movements of the head and neck are used for steering. By steering I intend to refer to movements to right and left in the horizontal plane.

In the case of vultures and cheels movements of the head frequently occur. But careful examination shows that these movements have nothing to do with steering. A cheel may turn its head to one side and still remain travelling in a straight line. Or a cheel having some food in its claws may lower its head, and bringing forward its feet, may tear and eat the food without interruption of its gliding flight. When vultures are starting their circling flight it is interesting to notice how little they appear to attend to what they are doing. Turning their heads to one side or the other as they watch other birds or look at the ground below them, seems to have no effect on the regularity of their course.

I purpose describing my observations relating to the functions of the tail in a later chapter, and shall then show that adjustments of this organ are not used to produce steering movements in the horizontal plane.

A statement has recently appeared in a popular paper to the effect that birds can steer by lowering one foot or the other. This opinion does not appear to be based on any serious observation. As I shall afterwards show, vultures do lower their feet when preparing to descend in certain cases. Sometimes one foot may be lowered a short time before the other. Vultures can, and usually do, steer from side to side without lowering their feet, and if they do lower one foot any steering effect produced is certainly infinitesimal. Hanging down the feet may act as a brake, but, as I shall explain later, this is not the most important method of checking speed that is used in descent.

I first obtained a clue to the nature of steering movements by observing the flight of the black vulture, in which bird the movements are commonly of larger extent than in other species. By practice, my powers of observation have increased, so that I am able to observe steering movements in other species of birds. For obvious reasons the larger birds are the most suitable for making these rather difficult observations. But I have on one occasion been able to see the movement that I am about to describe as the "depression" in the wing of the green parrot, a very fast flying bird of comparatively small size.

If a black vulture is watched when ease-gliding, occasionally the tip of one wing will be seen to be depressed downwards momentarily and then raised at once to its original position. The range of movement may be three or four inches. This dipping downwards of the wing-tip occurs at about the same speed as one might turn over and turn back the page of a book. After this movement has been completed the bird begins to turn in its course towards the side of the wing tip that was depressed. After the movement there is almost time to formulate in words which way the bird is going to turn before the commencement of the turn can be recognised. That is to say, there is the appearance of a latent period between the movement and the resulting steering action. In my notes I originally described this movement as a dipping downwards of the wing tip. This phrase was soon abbreviated to "dip," by which term I propose to refer to the movement in future.

It is necessary to consider how the "dip" is brought about. The first possibility that suggested itself to me was that it was caused by some of the intrinsic muscles of the wing. But on examining the wing of a dead bird, it appeared to me that the range of possible movement at the carpal joint was less than my observations had led me to expect. It then occurred to me that perhaps what really happened was that the whole of the wing was rotated until the air pressed on its upper surface instead of on its under surface. It is conceivable that should this be the case the quill feathers would thereby be depressed and so cause the appearance of the dip, especially as it is likely that the less supported quill feathers of the wing-tip would thereby be most affected.

In order to decide between these two possibilities, I dissected the wing of a black vulture, and found that neither of the above suggested explanations is an adequate statement of the facts of the case.

None of the intrinsic muscles of the wing have any power of making a dip movement by direct action. But, on the under side of the ulna, I found three muscles that have the power of rotating the front edge of the outer part of the wing. Supposing the wing is extended horizontally, then, if these three muscles come into action, the front edge of the wing tip becomes depressed. That is to say, the wing tip is rotated round the axis of the wing. The rotation is in such a direction that the air ceases to press on the under side of the wing tip feathers. Instead, it presses or tends to press on their upper surfaces. Hence the tips of these feathers are bent downwards, producing the appearance of the dip movement. From the dorsal aspect of the wing two muscles may be seen that have the power of rotating the front edge of the wing tip in the opposite direction. These muscles come into action at the end of a dip movement, to return the wing tip to its original position.

I have also found these muscles in the wings of the common vulture, the Adjutant (*Leptoptilus dubius*) and the Sarus (*Grus antigone*).

(*To be continued.*)

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Newspapers by Aeroplane.

An enterprising newspaper made arrangements with Gustav Hamel to carry several bundles of newspapers from the Hendon Aerodrome to Southend on Saturday last. The newspapers were rolled up and packed on the Blériot machine, and the aviator started off, but he had only got as far as Hammersmith when the heavy thunderstorm broke over London and caused him to come down.

CARRYING NEWSPAPERS BY AEROPLANE.—Mr. Gustav Hamel "autographing" some of the copies of the *Evening Times* at Hendon on Saturday last just prior to his attempt to carry them by aeroplane to Southend. As recorded elsewhere, Mr. Hamel gave up the flight soon after the start. At the left of the picture, in the cap, is M. Petit Pierre, the victim of the lunatic Hanot who so wildly shot at the spectators and others on Saturday evening at the Hendon Aerodrome. This picture was taken only a very short period before the crime was committed.

A Study of Bird Flight

By Dr. E. H. Hankin, M.A., D.Sc.

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FIG. 14 represents diagrammatically the structure of the wing tip, A–B is the axis of the wing, I to X are the large wing tip feathers, usually known as the primary quills. Of these I to IV are attached to the phalangeal bones, C, forming therewith a practically solid mass. These first four quills may conveniently be described as the "phalangeal quills." The remaining primary quills (V to X) are similarly attached to the metacarpal bone, D. These quills may, therefore, be described as the "metacarpal quills." The point of attachment of the metacarpal quill mass to the rest of the wing is indicated at E. The phalangeal quill mass is articulated at the point, H, to the point, F, of the metacarpal mass. That is to say, E is the carpal joint, and H and H represents the metacarpal joint.

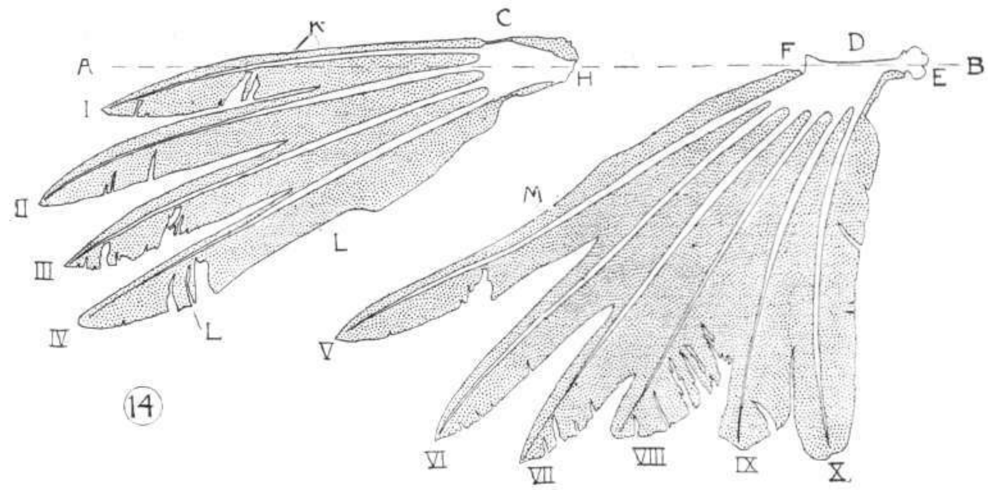

Fig. 14.—Structure of wing-tip of vulture. A—B, axis of wing. C K L, phalangeal quill mass, consisting of first four primary quills, I, II, III, IV, which form an almost solid mass with the phalangeal bone mass, C. The phalangeal quill mass is articulate at H to the point, F, of the metacarpal quill mass, M D. This latter consists of the fused metacarpal bones, D, to which are firmly attached the remaining primary quills, V, VI, VII, VIII, IX, and X. These quills may conveniently be termed metacarpal quills. The metacarpal quill mass is articulated at E, the carpal joint to the main part of the wing. For the sake of clearness, the alula or bastard wing has been omitted.

If the wing is extended horizontally, movement at these two joints may take place in the horizontal plane by the action of various flexor and extensor muscles. In birds there is no muscle that can bend the wing tip downwards by direct action. As I shall show in a later chapter, in bats there is such a muscle, which can bend the wing downwards at the carpal joint, and is used in flapping flight at the end of each downstroke. In birds, any appearance of bending downwards at the carpal joint can only be due to indirect causes, such as pressure of air on the upper surface of the wing. Slight rotation round the axis of the wing can occur at the carpal and metacarpal joint, and is so produced by the muscles that I am about to describe.

Let us suppose that the diagram (Fig. 14) represents the two parts of the wing-tip of the left wing as seen from above. The arrangement is such that the inner feathers overlap the outer feathers. That is to say, for instance, the edge M of quill V overlaps the edge L of quill IV. In the case of the common vulture when making a dip movement of limited extent, a gap of about an inch may be seen to occur momentarily between the points M and L. Therefore the rotation of the point K downwards does not immediately result in L being elevated. On the contrary, owing to the rotation, the whole of the phalangeal mass ceases to be pushed up by the air and therefore becomes depressed. If a small dip of this nature passes on into a full dip, then this gap closes up and there is an appearance of the hinder ends of the quills becoming elevated. My diary contains seven instances of observa-

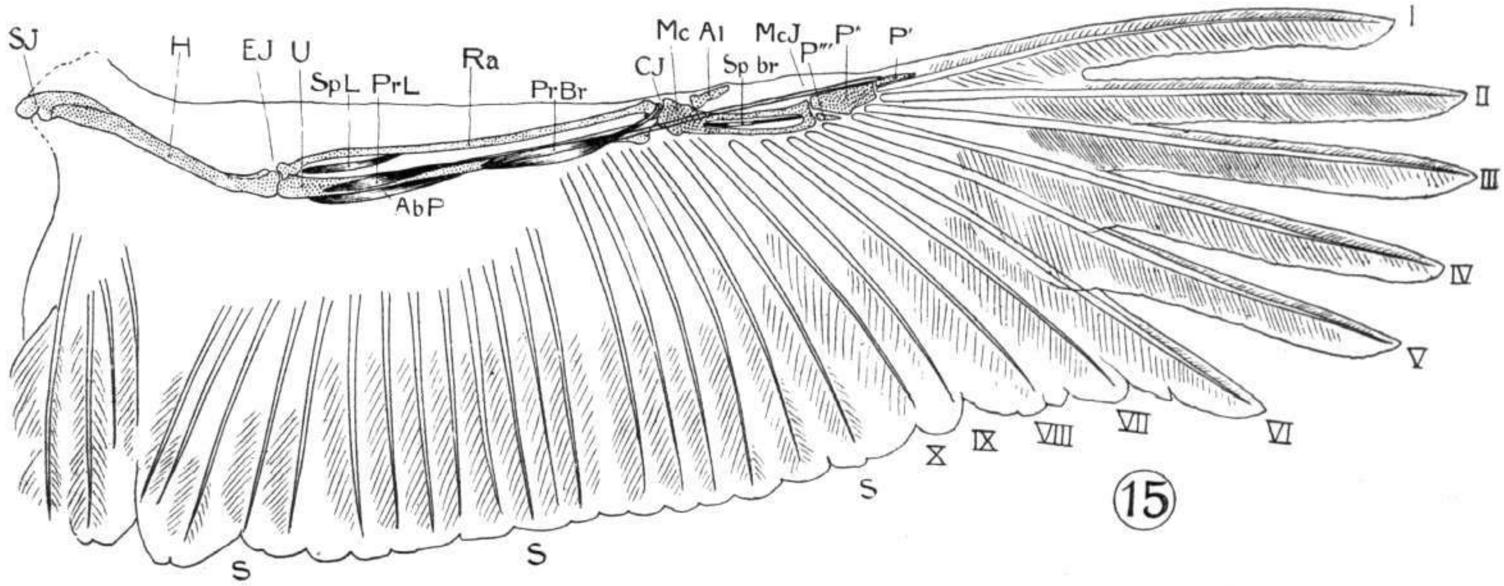

Fig. 15.—Dissection of left wing of Black Vulture (Otogyps calvus) seen from below, showing muscles concerned in rotation of wing-tip. S J, shoulder joint; H, humerus; E J, elbow joint; U, ulna; Ra, radius; C J, carpal joint; Mc, metacarpal bone; Al, phalanx of first finger of alula; Mc J, metacarpal joint; P'', P'', phalanges of middle finger; P''', phalanx of third finger. I, II, III, IV, phalangeal quills; V, VI, VII, VIII, IX, X, metacarpal quills; S, S, S, secondary quills; Sp L, supinator longus; Sp br, supinator brevis. The tendons of these two muscles are not shown. Pr L, pronator ongus; Ab P, abductor pinnae; Pr Br, pronator brevis. The tendons of the pronator longus and of the abductor pinnae are shown inserted into the phalanx P''.

tion of this "phalangeal quill gap." Since the date of the last entry I have seen it on many occasions. Once I have seen it in the case of a black vulture. I have observed it both in circling, ease-gliding and in the gliding periods of flap-gliding.

This dip movement of limited range, in which the phalangeal mass only is moved, I propose to term the "half-dip." During the

Fig. 16.—View from in front of phalangeal quills.

half-dip, owing to the rotation, air ceases to press on the under surface of the feathers. But rotation is not carried far enough for air to press on the upper surface of the quills. Hence, during the half-dip, the feathers being relieved from air pressure, whether from above or below, take on their natural curvature as shown in Fig. 16. A half-dip movement causes a steering effect in the same direction as a full dip but to a less extent. I have been able to see this steering effect on several occasions, but perhaps more often than not the effect is too small to be detected.

It may be suggested that during a dip the air acts as a drag, by pressing on the upper surface of the quills. This suggestion is an easy explanation of the steering effect. But the phenomenon of the half dip suggests that it is not sufficient. It is possible that facts to be described in later chapters may be considered to indicate that some more deep-seated action is involved.

The chief muscles concerned in rotating the wing tip are shown in Fig. 15. This may be supposed to be a diagrammatic view of the under side of the wing, in which various muscles not concerned with wing tip rotation have been removed for the sake of clearness. The following are the names that I propose for the muscles, with a short description:—

1. "Pronator phalangis." This muscle arises from near the base of the ulna. Its tendon is inserted on the base of the middle phalanx.

2. "Abductor pinnae." This muscle arises from a tendon that connects the elbow and carpal joints. It is inserted on the outer side of the phalanx. Pulling the tendon of this muscle has a slight effect in rotating the wing-tip but also tends to advance the first primary quills.

3. "Pronator metacarpi." This muscle arises from the under surface of the distal part of the ulna. Its tendon passes in a curved course over the carpal joint and is inserted on to the base of the metacarpal bone.

4. "Supinator longus." This muscle arises from the dorsal surface of the radius. Its tendon (not shown in the diagram) is inserted on the middle phalanx. A small branch of its tendon is inserted into the alula. The action of this muscle is to rotate the front edge of the wing-tip upwards, that is to say to return it to its original position after a dip movement.*

5. "Supinator brevis" is a short supinator muscle lying in the hollow of the metacarpal bone mass.†

A second kind of steering action also occurs. This is visible as a momentary depression of the whole wing. The result is that the bird turns towards the side of the wing that is depressed. I propose to bring forward evidence bearing on the question of the nature of the depression movement in Chapter XVIII.

Perhaps more often than not in the smaller soaring birds, and sometimes in larger birds, the dip is combined in one movement with depression of greater or less extent.

CHAPTER IX.—Diving. Rotation round Transverse Axis.

A tendency to dive head downwards, or else losing speed to glide backwards and descend tail foremost is or has been shown by various gliders and aeroplanes.

Soaring birds behave as if free of this tendency. But they can dive voluntarily when they wish to descend from a height at speed. A study of the method by which they check their speed when thus diving will be found to be of interest and to lead to the suggestion that they have a perfect method of preserving their longitudinal stability far superior to the use of elevators or horizontal rudders as seen on aeroplanes.

* The branch of the supinator longus tendon to the alula was missing in the only specimen of the sarus (*Grus antigone*) that I have dissected.

† Rotation of the wing-tip can be produced by pulling the tendons of these muscles. To see this rotation it is necessary to use a bird of large size. The movement is much more easily seen in a bird of ten foot span than in a bird of seven foot span. The bird should be freshly killed, and the structure of the wing should be disturbed as little as possible. Only a small portion of the basal part of the tendons should be dissected out.

The following extracts from my diary illustrate the general phenomena shown by birds when diving:—

February 14th, 1910.—At 3.36.—A light west wind and a few isolated cumulus clouds. At the time of commencing my observations only one vulture was visible. It was flex-gliding. Its height was measured with the telemetre and found to be 700 metres. While watching it, I noticed that its speed was greater than usual, and I at once made a measurement. It was found to be 40 metres per second (that is to say 89 miles an hour). It was then seen to be diving downwards, its track making an angle of perhaps 20° or 30° with the vertical. After I had made the measurement, its speed increased rapidly and greatly. At a height of about 100 metres above the earth it suddenly checked its dive, swerving somewhat from its course while so doing. The bird was then seen to be descending at moderate speed with its wings extended in the horizontal plane and slightly flexed. Its body and legs were hanging down below the level of the plane of the wings, and as it descended it was swaying to and fro like a parachute till it reached the earth. Within one or two minutes about 30 other vultures dived and landed in the same way. Then a vulture was seen which after its dive, and after it had commenced "parachuting," drew up its legs and flex-glided off, having apparently changed its mind. The vultures that had settled rose at 3.45 circling with flapping. Above 50 metres height they circled without flapping. They drifted to leeward and passed me at about 200 metres height. The "windward dip" was seen in several. Also half dips of the outside wing on the windward side of the circles. Above 200 metres height the vultures gained height rapidly.

Though I was able to follow several of the diving birds with the binocular it was quite impossible for me to see the method by which their speed when diving was so suddenly decreased. To be able to see how this is done it is necessary to be standing near the carrion so that the birds are seen approaching. Thus having an end on view of their track more can be observed than when they are diving at a speed of probably more than a hundred miles an hour across the field of view. I had seen the actual adjustment used for checking speed when diving some years ago. In view of my increased acquaintance with the subject it was desirable for me to see these movements again. A fortunate chance gave me this opportunity. The following description is from my diary:—

20th March, 1910.—At 5.0.—I arrived at Futteypur-Sikri just as the body of a leopard, that someone had shot and skinned,

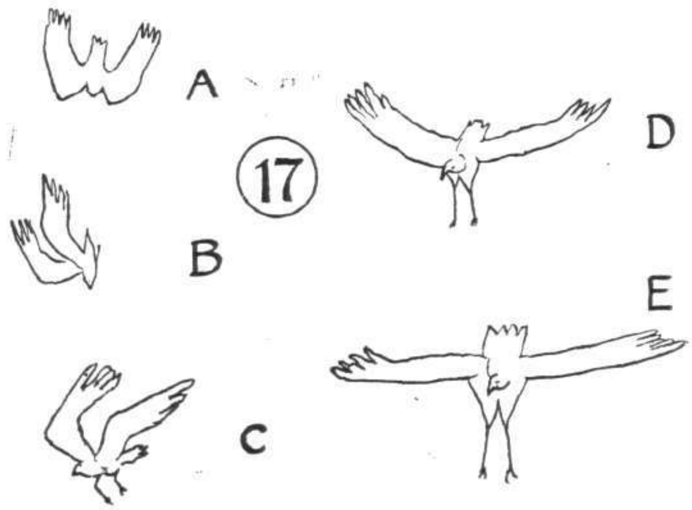

Fig. 17.—A vulture diving and checking speed. A, position assumed in diving; B, wings, still flexed, placed in dihedrally up position. Owing to the inertia acting through the centre of gravity and the resistance of the wing-tips forming a couple, the bird rotates to the position shown at C. In this position, instead of descending head first, it is descending legs first, with greatly increased resistance.

had been thrown over the edge of the hill a few yards away from the terrace of the dawk bungalow. Vultures were descending. For the most part they came from a distance, gliding downwards at a small angle of descent. One was watched nearly overhead diving downwards. When about 200 metres up it placed its wings, still flexed, in the dihedrally up position, so that the two wings made with one another a dihedral angle of between 90° and 100°. The bird also began to extend its legs; consequently it rotated in the air round its transverse axis, so that instead of descending head first it descended legs first. As, in consequence, the speed decreased, the dihedral angle of the wings diminished.

When near my level the wings were nearly flat (that is to say, extended horizontally, with no dihedral angle). The legs and also the body were hanging downwards below the level of the wings. All the birds as they descended glided to leeward of the dead leopard, so that when landing they were gliding up wind. The wind was west and very light, slightly moving the leaves of the trees. (How these birds knew the direction of the wind is a question more easily asked than answered.) The birds that arrived flex-gliding from a distance began to drop their legs and allow their bodies to hang down when about 50 metres up, and when from 50 to 100 metres to leeward of the leopard. In every vulture observed the "alula" was seen to be extended. In one or two instances the alula of one wing was seen to be suddenly rotated upwards. In spite of my best endeavour, it was impossible for me to observe whether this rotation affected both alulæ at the same time. The observed movement of the alula must have been over 2 centimetres of its front edge. One vulture, when gliding down, suddenly slightly increased the flexing of both wings simultaneously. This produced an immediate drop of several feet, nearly vertically, obviously with the intention of getting to the ground without overshooting the mark. The drop was checked by renewed extension of the wings.

The important point in this description is the fact that the diving vulture placed its wings in the dihedrally up position to cause rotation round the transverse axis. On other occasions I have seen black vultures and cheels when playing together in the air make short dives which were checked by placing the wings in the dihedrally up position.

Fig. 17 shows diagrammatically the changes in the disposition of the wings that result in checking the speed of diving. The explanation of the rotation is obvious. When the wings are placed dihedrally up, as at B, the inertia of the bird acts through the centre of gravity pulling the bird downwards or nearly downwards. The resistance of the wings must be acting in the opposite direction. The two forces do not act in the same straight line. Hence there must be a couple that rotates the bird to the position shown at C.

I will now consider the effect of changes in the dihedral angle. The change from the dihedrally-up to the dihedrally-down positions can often be seen in cheels, though in these birds it is usually not very great in extent. One of the first things I noticed on beginning my observations on cheels was that the dihedrally-up position is seen in circling especially on the up-wind side of the circle. I also saw that it was assumed at the end of a horizontal glide and that it immediately resulted in a gain of height. I learnt to associate the dihedrally-down position with loss of height and increase of speed. I once saw a cheel gaining height in several successive circles, with its wings, so far as I could see, in the dihedrally-up position all round the circle. Then, without gain of height, it described a circle with the wings either flat or slightly dihedrally down. Then it made a long glide in a straight line, descending gradually, with the wings dihedrally down and with clearly seen increase of speed.

(To be continued.)

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THE AVERAGE WEATHER OF SEPTEMBER.

By T. F. MANNING.

IN September the weather conditions begin, as a rule, to become somewhat adverse to the flying man.

This amazing summer, of course, has shown no regard for averages, and how it will influence the general character of the first autumn month we cannot guess. Normally there is less rain in September than in either July or August; but this year we may reasonably calculate on a reversal of the normal relationship, and perhaps for a greater than the average rainfall. Usually the first three weeks have considerably fewer rainy days than the corresponding period in August, but with the fourth week a decided increase sets in.

The fact of most importance to the airman is the very great increase which occurs in the number of fogs and mists. Both light fogs and dense fogs are three times as numerous in September as in August, and nearly seven times as numerous as in July. They differ from winter fogs, however, in the fact that they occur chiefly in the mornings and evenings. They increase steadily from the beginning to the end of the month, and while the odds are about 2 to 1 against a fog in the first week, the chances are 11 to 10 in favour of a fog during the last week. The following figures show how badly September compares with August in this respect:—

Fogs in a Hundred Years.

	August.	Sept.		August.	Sept.
1st week ...	23	55	4th week ...	41	110
2nd week ...	13	85	Whole month	122	374
3rd week ...	29	97			

Storms are almost as infrequent in the early part of September as during the summer months, but in the fourth week they rapidly increase. The fourth week over a series of years is twice as stormy as the first week; but, even so, the chances are 3 to 1 against a gale during this week in any year. In the whole month there are 11 gales in 10 years; this is an increase of 25 per cent. over August.

Hail is very rare in September—one fall in six years, and snow is scarcely ever seen in the south of England during this month, although one or two falls have been recorded.

Thunderstorms may still be expected, but they are only half as frequent as in August, and average just one for the whole month. But this phenomenon is so very uncertain that we might have several thunderstorms or none in any one September.

With this month the most favourable flying season comes to an end. The falling temperature brings fogs and mists, gales increase in number and violence, sunshine and daylight decline, and cloudy or entirely overcast skies become much more common.

The following figures show the relative average weather of August, September and October. They give the number of events occurring in each month during a period of ten years:—

	August.	Sept.	Oct.
Ten years' gales	9	11	16
,, fogs	12	37	50
,, dense fogs	2	6½	10
,, thunderstorms	21	10	3½
,, hail-storms	1½	1¾	1¾
,, rain-days	129	123	150
Average rainfall (Greenwich) ...	2·34 in.	2·15 in.	2·58 in.
Mean temperature (Greenwich) ...	61·6	57·2	50·0
Hours of sunshine (Greenwich) ...	189	141	93
Degree of humidity (Greenwich)...	76·3	80·2	85·0

Table of Weather Phenomena in September.

The figures show the numbers of each event in one hundred years.

Day.	Gales.	Fogs.	Dense Fogs.	Snow.	Hail.	Thunder.	Mean Temp.	Rain Days.
1	3	8	1	–	1	5	59·7	37
2	2	6	1	–	–	3	59·7	49
3	1	8	1	–	–	5	59·6	44
4	1	9	1	–	–	3	59·4	37
5	2	8	1	–	1	3	59·3	40
6	3	11	1	–	2	8	59·1	51
7	4	5	—	–	1	7	58·9	40
1st week ...	16	55	6	0	5	34	—	298
8	2	12	2	–	–	5	58·7	40
9	5	10	2	–	2	4	58·5	43
10	4	12	2	–	–	3	58·3	43
11	4	15	–	–	1	3	58·1	32
12	6	9	2	–	–	3	58·0	32
13	4	17	3	–	–	3	57·9	27
14	2	10	–	–	–	3	57·8	34
2nd week ...	27	85	11	0	3	24	—	251
15	3	16	2	–	2	4	57·7	32
16	5	10	3	–	1	1	57·5	35
17	1	19	4	–	–	4	57·3	41
18	3	13	2	–	–	3	56·9	41
19	4	15	1	–	1	1	56·5	37
20	2	9	2	–	2	1	56·1	38
21	2	15	3	–	1	5	55·7	54
3rd week ...	20	97	17	0	7	19	—	278
22	2	14	3	–	–	3	55·4	40
23	8	15	2	–	1	4	55·3	47
24	4	12	2	1	–	4	55·1	51
25	5	17	4	1	–	–	55·0	41
26	5	14	3	–	–	2	54·9	38
27	6	16	6	–	–	1	54·9	46
28	4	22	4	–	1	3	54·8	48
4th week ...	34	110	24	2	2	17	—	311
29	6	13	3	–	1	2	54·6	49
30	9	14	5	–	–	4	54·4	48
	112	374	66	2	18	100	57·2	1,235

A Study of Bird Flight

By Dr. E. H. Hankin, M.A. DSc.
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TOWARDS sunset, when the air near the earth appears to lose its power of permitting soaring flight, soaring birds may be seen returning to roost by flap-gliding flight—that is to say, by flapping flight alternating with periods of gliding. Each glide may last from 5 secs. to 20 secs.; the periods of flapping may be 5 secs. or less. During the glide the bird appears to travel horizontally. Sometimes there is a slight loss of height at the commencement of the glide and a slight gain of height at the end of the glide—that is to say, there are no grounds for assuming that speed is maintained at the expense of height. On the other hand, it is probable that height is maintained at the expense of speed. In other words, it is probable that during the glide speed is being lost, and that the angle of incidence of the wings is being gradually increased by increase of the dihedral angle of the wings. In the case of cheels, the wings are flat or slightly dihedrally down, but towards the end of the glide the wings may be seen to be dihedrally up. This change of disposition may be seen to be accompanied by a slight gain of height; immediately after this gain of height flapping recommences. In the case of vultures, the wings may be either flat or dihedrally up. The flat disposition seems to be adopted in unsoarable air, and if the bird is about to settle. It may rarely be seen also under conditions that may be regarded as preparatory for flex-gliding. The dihedrally up position appears to be adopted by vultures more often in soarable air and when the bird is about to circle. In the case of flying foxes (*Pteropus medius*, a bat of 44-in. to 51-in. span), which occasionally may be seen in gliding flight for short distances, if the wings are held dihedrally down there is loss of height and increase of speed. For gliding horizontally, or nearly so, this species of bat keeps its wings "arched"—that is to say, concave from side to side.

I have left till now consideration of an important directive movement to which I propose to give the name of the "double dip." This is the easiest movement to observe. It is frequently seen during flex-gliding and at the commencement of a flex-glide.

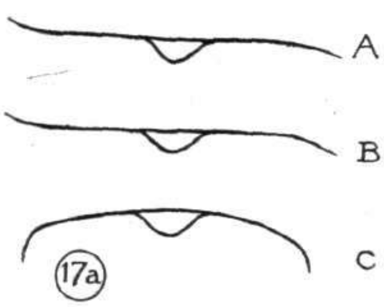

Fig. 17a.—End on view of bird. (*a*) During half-dip; (*b*) During full-dip; (*c*) During double-dip.

In the "double dip" both wing tips (Fig. 17a) are dipped downwards to an equal amount and the wings are during the movement nearly always placed in the dihedrally down position. The result of the "double dip" is that the bird rotates slightly round its transverse axis. It therefore makes a dive downwards. This dive is at once checked as the wings return to their original position. The result of this short dive is that the bird increases its speed, and if it is flex-gliding in soarable air this increase of speed is maintained. I have only been able to observe this rotation on three or four occasions. The following are examples:—

February 13th, 1910.—At 12.36.—A black vulture was seen end on when it was beginning a flex-glide in my direction. The double dip was seen to be accompanied by and apparently to cause a tilting of the body, so that, during the dip, it pointed downwards at an angle of about 45°. This momentary dive seemed to be the initial cause of the increase of speed, which speed was maintained as the bird regained its horizontal position.

March 30th, 1910.—At 4.20.—A brown vulture starting a flex-glide was seen to incline its body downwards during the double dip.

In Fig. 18 is shown diagrammatically the outline of a bird during the double dip. The inertia of the bird may be considered to act through the centre of gravity, at A. The resistance of the wings may be considered to act through the point, B. There must obviously be a couple between these two forces tending to rotate the bird downwards, as shown by the arrow, C.

In Fig. 19 I have shown the position of the wings when in the dihedrally up position. In this case the inertia acts at A, and the resistance of the wings at B, resulting in a couple that tends to rotate the bird upwards, as shown by the arrow, C.

We have now considered two cases of rotation round the transverse axis, namely, rotation upwards, as used for checking a dive, and rotation downwards, as in a double dip. In both these cases rotation round the transverse axis is caused by changing the relation of the centre of resistance to the centre of gravity of the body. These instances may be regarded as extreme cases. The same method of rotating the body appears to be employed in cases that are not extreme.

As already stated, a cheel wishing to glide downwards places its wings in the dihedrally down position. If it wishes to increase the steepness of its descent it elevates the tail, which is closely furled. If the tail feathers have been cut off, the posterior portion of the body can be seen to be elevated—that is to say, there is no reason for believing that the elevation of the tail acts by any effect of air currents on its surface. It obviously must act by further increasing the distance between the centre of gravity and the centre of resistance of the wings. I have also seen elevation of the tail for gliding downwards in vultures and other species of birds.

Cheels when ease-gliding not infrequently show up and down movements of the furled tail. The range of movement of the end of the tail may be an inch or more. This tail jolting is seen especially in irregular winds and when the bird is travelling comparatively slowly. It is never seen in fast flex-gliding. Occasionally in irregular winds each upward jolt of the tail is accompanied by

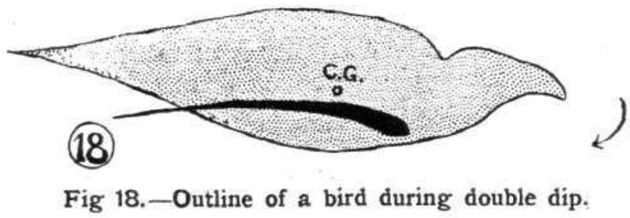

Fig 18.—Outline of a bird during double dip.

increase of the flexing of the wings, that is to say by an adjustment that is associated with increase of speed. I have seen slow up and down movements of the tail in the case of the Lammergeyer when gliding at low rate. On one occasion I saw a sudden tail jolt in the case of a black vulture. This movement was associated with the wings being placed momentarily in the dihedrally down position.

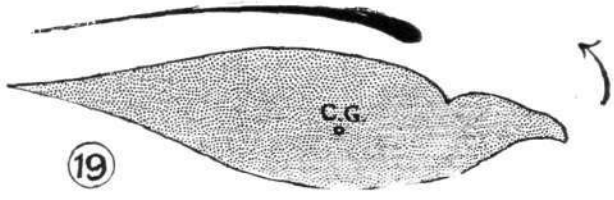

Fig. 19.—Outline of a bird with wings dihedrally up.

In the case of "tailless cheels" energetic jolting movements of the hinder end of the body occur especially in an irregular wind. It is not likely that these movements are purposeless. The facts brought forward in this chapter suggest that they have to do with maintenance of equilibrium round the transverse axis.

Thus it appears that birds can alter the distance between their centre of gravity and their centre of resistance. They do this by changes in the disposition of the tail and hinder part of the body and by changing the dihedral angle of the wings. In a later chapter I shall have to describe another method of producing rotation round the transverse axis.

CHAPTER X.—Can Soaring take place in a Dead Calm?

If it is admitted that soaring occurs when the air at the ground level is calm or nearly calm, what proof is there that wind is equally absent at the height at which birds are circling?

In the case of cheels this height may be only three or four metres above the roof of my house. In the case of vultures the height is slightly greater. If it is calm on the roof of my house the air is not likely to have much velocity at so small a height above it.

Small whirlwinds or dust devils frequently occur in Agra on warm days when the air is nearly calm. A dust devil consists of a column

of dust in rapid rotation. It may be three or four metres in diameter and may reach a height of several hundred metres. At its upper extremity the column of dust expands, forming a light yellowish cloud which persists for some time after the column of dust from which it arose has vanished. The air in the immediate neighbourhood of a dust devil appears to be rising, for I have seen a piece of paper carried up in a slanting direction, in the neighbourhood of a dust devil, to a great height, possibly 800 metres, before it went out of sight when followed with a binocular.

Soaring birds seem to take no notice of these dust devils, as a rule. On one occasion (December 11th, 1910) I saw a group of cheels apparently within the sphere of influence of a dust devil. Five cheels were ease-gliding at a height of about 80 metres and at about 100 metres distance. A dust devil passed slowly by about 200 metres away from the birds. The cheels gradually ascended to a height of about 200 metres. Then they flex-glided away in different directions. The ascent of these cheels was not due to circling, that is to say to ordinary soaring flight, because firstly there was no leeward drift, secondly they rose as a group keeping more or less their relative distances, and there were no stragglers. Hence it is probable that they were lifted by a rising current of air connected with the dust devil.

On several occasions during October, November and December of 1909 (but not during the same months of 1910) I saw pieces or jawar leaf or pieces of grass floating in the air. There can be no doubt that they had been carried up by dust devils and that when I saw them they were falling. In all cases their horizontal movement was very slow, indicating that at the height at which they were observed the wind was as light, or nearly as light as it was near the earth. Knowing the probable size of these pieces of leaf, it was possible to make a rough estimate of their height which on some occasions may have been as much as 200 metres above ground level.

On the 8th February, 1910, I saw a boy's kite floating in the air at a height far above that at which it is likely to have been flown. As these native kites are nearly always of the same size, I was able to make an estimate of its distance. It was at about 1,000 metres distance. It was probably 500 metres above the earth. It was only visible to the naked eye when the sunlight fell on its white surface. The wind was so light that its direction of fall made an angle of 10° to 20° with the vertical. It was watched till it went out of sight behind some trees. Several birds were circling and flex-gliding near. It may be explained that these native kites are so light that they can be flown in a wind that is scarcely perceptible.

I have nearly a dozen entries in my diary of pieces of paper or feathers being seen floating in the air. On one occasion a feather was seen in the midst of a cluster of circling cheels, and its motion was noted as being imperceptible. Once a feather was seen to drop off a cheel, and showed by its almost complete lack of movement the small amount of movement in the air. During October and November at Jharna Nullah, when one or two thousand birds may be circling and gliding together, it is rarely necessary to wait for more than a few minntes to leeward of the clusters of birds to see one or more feathers floating in the air.

In the calm weather that often occurs in October and November after the close of the monsoon season, smoke from factory chimneys can be seen rising vertically to an immense height. I have seen this smoke reach a height that I estimated at being nine times the height of the chimney. The chimney is 135 feet high, hence its smoke must have reached a height of 430 metres. Vultures in the neighbourhood were circling at lower levels.

On a calm morning during the cold weather a light mist, composed, I believe, of smoke and dust, commonly lies over the city and country. It is not very thick. Usually a factory chimney is visible through it three miles away. The smoke from this chimney can be seen dimly rising through the mist, and spreading out in all directions horizontally, forming a layer like a thin cloud. As the sun gathers power the smoke may be seen piercing this layer, and rising vertically. To all appearances the air is completely calm. It is very striking to see the cheels rise circling in and through this mist. Their time of starting is not in the least delayed by the complete absence of wind.

The appearance of rest in the air is, however, deceptive. Rising eddies of air formed under the influence of the sun's rays are already beginning. These "heat eddies," as I propose to call them, can best be seen through a binocular held firmly in a clamp. As the heat eddies develop the edges of the flat roofs of buildings may be seen to acquire an appearance of shimmering and quaking. The eddies resemble waves far more mobile and active than the waves of an angry sea. The slightest wind causes these eddies to appear to run along the lines of the buildings. Observation of these eddies can be used as a test to see whether or not wind exists. It is a test far more delicate than the sense of touch, and even perhaps than observing the movement of smoke. On two occasions during the cold weather of 1910-11 I have seen complete absence of wind as tested by heat eddies, and on each occasion the circling of cheels began at its normal time.

In view of the above facts, there can be no doubt that it is inaccurate to describe the soaring bird as getting its energy from the wind. In other words, in attempting to discover the source of the energy of soaring, the movement of tangible masses of air that we know as wind must be left out of account.

CHAPTER XI.—Description of circling of Cranes.

A remarkable and important characteristic of circling flight, namely, its regularity, can only be seen and appreciated with difficulty in the case of vultures, but can be readily observed in the case of cranes. I was once watching between 50 and 100 cranes starting from the river bed beyond the Taj. They were flap-gliding in large circles until they reached a height of between 100 and 200 metres. They then circled without flapping. Their leeward drift indicated that the wind was north-west. As I had been under the impression that the wind was west (it was very light at the time), I at once sent a boy to fly a kite, and found thereby that the wind was N.W. as had been indicated by the drift of the circling cranes.

In the case of vultures the point round which they circle is situated somewhere near the centre of the cluster of birds. In the case of cranes this central point is not inside the cluster but outside it, at a distance of perhaps 200 metres or more from the group of birds.

The birds form a compact group as they glide round this central point. The remarkable feature of their flight is the regularity and exactness with which they keep their distance from one another. If anyone was shown such a group of cranes through a binocular without being told what he was looking at he might easily believe that he was looking at a number of dead birds pinned on to a wall, all pinned on with their wings in exactly the same position. While the cranes were on the up-wind side of their track they looked black in colour against the background of pale blue sky. As they neared the windward side and gradually turned, they appeared to diminish in size till suddenly they were visible in end on view, each bird then looking like a black inclined line with a central dot representing the body. The change from the side view to the end on view appeared to take place within one or two seconds for the whole group. As the birds turned from the windward side to the down-wind side of their track, the change was equally sudden. Within one or two seconds, as it seemed to me, every bird had changed in appearance, and now showed the upper surfaces of their wings, which appeared nearly white in colour from the reflected sunlight. Towards the end of the down-wind glide perhaps one or two birds showed occasionally some slight deflection (not beating) of their wings. Then came the sudden change to end on view that the birds presented along the leeward side of their track. While thus circling the cranes were rapidly gaining height, in a quarter of an hour reaching a height of about 1,200 metres. They then reversed the direction of their circling once or twice, still keeping in a compact group. They then flex-glided away in a northerly direction. In so doing they arranged themselves side by side in a long line dented in the middle, like a letter V, but with an obtuse angle, and with the apex forward. The birds were at regular distances, and kept their distances with almost the same marvellous regularity as they did when circling. Their flex-gliding was canted. Every bird was canted to the same degree, and remained so till they were out of sight. (Date of observation, 28th March, 1910, at 4.15.)

This regularity of the gliding flight of cranes when circling or flex-gliding has a certain theoretical interest.

It has already been shown that the soaring bird does not get its energy from the wind. Therefore, it must get its energy from the air. Unless the bird actually changes the air by its passage, it is impossible for it to get energy from the air if the air is homogeneous. Therefore soarable air must be heterogeneous. Because cranes when soaring do so with regularity, therefore they must get their energy from the air at a constant rate. Therefore the heterogeneity of the air must be fine grained. This conclusion may be expressed more clearly in another way. My friend, Dr. Morris Travers, of the Indian Institute of Research, suggested to me that possibly soaring birds might get energy by meeting eddies and extinguishing their motion. The suggestion appears to me of interest, as the first formal theory of the nature of soarability that I have heard of that has any regard to the facts of the case. Supposing it is true, then since the bird gets energy by meeting eddies at a regular rate, such eddies must be small in comparison with the size of the bird, and must be uniformly distributed. It is likely that after bringing forward further evidence, I may bring forward another theory of the nature of soarability.

In view of the results already described, it is certain that soaring flight cannot be due to the bird taking advantage of chance currents of wind. Something of a more uniform and regular character must be looked for in soarable air. So far as the present evidence goes, it is logical to investigate any movements of the nature of eddies in soarable air, even if they are of microscopic or ultra-microscopic size.

(*To be continued.*)

A Study of Bird Flight

By Dr. E. H. Hankin. M.A. DSc.

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CHAPTER XV.—**The Source of the Energy in Soaring Flight.**

SOARABILITY in Agra occurs in three types, which may be described as follows:—

1. "Sun soarability." This is observed in fine weather, chiefly in the cold and hot seasons. If, though the weather is otherwise fine, there is a thin layer of cloud over the sun the soarability of the air may be diminished. Sun soarability may be abolished by heavy cloud shadow. Further, the fact of this kind of soarability commencing at a definite hour in the morning, earlier in summer and later in winter, may be regarded as a further proof that the source of the energy involved is to be found in the rays of the sun. Sun soarability is not diminished by absence of wind.

2. "Storm soarability."—This form of soarability may be observed in the wind preceding a dust storm or thunderstorm, and also at the sides of a thunderstorm. It is usually observed in the presence of cloud and wind. The facts that it may occur after sunset, and shortly after sunrise, are proofs that sun energy is not involved, at least directly. Stormy winds may occur that are completely unsoarable. In such cases sunshine and signs of electrical disturbances are absent. Cheels rising into the air in winds of this nature are almost instantaneously blown to leeward. That is to say the only energy available (apart from flapping) was the energy they possessed in virtue of their having been seated on the earth before rising into the air. As soon as this energy was exhausted they had to glide steeply or else were blown to leeward.

3. The above generalisation suggests that soarability may depend on what may provisionally be regarded as two sources of energy. Supposing these two sources of energy were operative together, each at less than full strength, and in varying proportions, it may be imagined that a form of soarability would be produced whose nature would be very difficult to determine. Perhaps this is the nature of the soarability that I have observed frequently in Agra during the monsoon season (July to September), and occasionally at the time of the cold weather rains (December and January). Perhaps this kind of soarability has come under the notice of other observers in certain cases. This "disturbed weather soarability" may vary, perhaps, from hour to hour in its nature. Less energy usually appears to be available than in typical sun or storm soarability. It appears to be less easily affected by cloud than is sun soarability. I have no proof that it is favoured or increased by absence of wind.

The facts already given may be regarded as presumptive proofs that sun energy is the source of the energy of sun soarability. I have now to describe some observations that I think will be regarded as demonstrative proofs of the connection between sun energy and sun soarability. These observations were carried out at Naini Tal during June, 1910.

Naini Tal is situated in the Himalaya Mountains at an elevation of between 6,000 and 8,000 ft. above sea level. The elevation of Agra is only about 500 ft. The air at Naini Tal is consequently more rarefied than that at Agra. It is therefore presumably less buoyant. But in the presence of strong sunshine the air in Naini Tal is at least as favourable for soaring flight as it is in Agra.

The species of birds studied in Naini Tal were the same as those on which most of my observations have been carried out in Agra, but with two additions. The species of crow present in Naini Tal has the power of soaring, at any rate in calm air, and in the presence of strong sunshine. The crow found in the plains of India is of a different species, and does not soar under any conditions. In Naini Tal I saw a few specimens of the "Lammergeyer" (*Gypaetus barbatus*), a vulture of 9 ft. to 9½ ft. span. It has a long tail, and is characterised by slow heavy flight. I have never yet seen in the flight of the Lammergeyer any sign of "relaxation of secondaries," an adjustment that will be described in later chapters as occurring in the flight of other species of vulture.

Gliding flight in mountainous country generally occurs in ascending currents of air. Despite this fact it will be seen that my observations made in Naini Tal lead to the clearest proofs that in soaring flight energy is taken from the air, and that it is somehow connected with the energy present in the sun's rays.

During the period of my observations (June, 1910), the wind was nearly always so feeble that ascending currents of air produced thereby were not sufficiently strong to support birds in soaring flight unless in the presence of sunshine or at least a strong glare of light. In Naini Tal cheels and vultures could often be seen circling when enveloped in thin cloud. Under heavy cloud, in which the amount of light was diminished, soaring flight did not occur. The observations on which this statement was based were mostly made near a slaughter house in Ballia Ravine, just below Naini Tal. I was fortunate in getting permission to use a ledge overlooking the precipitous side of the ravine by the police lines as a post of observation. At this point the Ballia Ravine is about 300 feet deep, and has a width of 1,100 feet. Numerous vultures were in the habit of roosting on trees or rocks on the side of the ravine nearest my post of observation. During the daytime wind is nearly always blowing up the ravine from the valley below, sometimes clear and sometimes carrying cloud. Often cloud could be seen in process of formation by condensation of the rising air. When this was the case the amount of sunshine or glare varied rapidly from minute to minute, causing clearly observable changes in the degree of soarability of the air. For instance:—

June 18th, 1910.—At Ballia Ravine. 3.2.—Two cheels were circling in thin cloud. The air current was seen to be slowly rising though the wind was not sufficient to be felt. As glare decreased from further accumulation of cloud overhead the cheels were observed to cease circling and began flap-gliding in circles. No change occurred at the time in the rate of movement of the air.

That is to say, as the glare of light decreased, the air became less suitable for soaring flight. The following is a similar case:—

June 26th, 1910.—At Ballia Ravine. 11.45.—Wind very feeble, only occasionally perceptible. Four vultures had been circling enveloped in thin cloud. As the cloud above them got thicker, they ceased circling and glided down the valley. Two turned back after going a short distance and settled. The other two glided on further till on reaching sunshine they again began circling.

The following extract from my diary is an instance of several successive changes in the degree of soarability occurring coincidently with changes in the amount of glare or sunshine:—

Sunday, June 12th, 1910.—At Ballia Ravine. 11.0.—Wind occasionally enough to move leaves. No puffs or eddies. Sunshine near. Two cheels circling. One vulture circling with occasional flaps.

11.15.—Another patch of sunshine. A black vulture, a white scavenger vulture and some cheels began circling. Shortly afterwards, as cloud rolled up overhead, these birds settled or disappeared.

11.32.—The cloud mass overhead was thinning so that there was a strong glare. A cheel seen circling in thin cloud. As the cloud lifted a group of 24 vultures were seen circling (in sunshine) over a hill two miles distant.

11.40.—Sun shining. The 24 vultures glided to the neighbourhood of the police lines. Some settled. A few flex-glided back down the valley and circled in front of an advancing cloud.

12.6.—This cloud was coming near. Two vultures were watched circling in this cloud for about three minutes. They disappeared as the cloud became thicker. This was wet cloud that deposited small drops of water on my clothes.

12.12.—Heavy cloud overhead, so that it was getting comparatively dark. Cheels settling.

12.29.—Though I was still enveloped in cloud the sun was shining sufficiently to throw faint shadows. Four cheels circling near.

12.30.—Six cheels circling near.

12.32.—Many cheels circling. Vultures starting and gliding down the valley. These vultures, at time of starting, were enveloped in thin cloud.

12.34.—Thick cloud overhead and noticeably darker. Cheels near had all settled. No cloud below in ravine.

12.35.—More glare. One cheel up circling. Less wind now, not enough to move leaves.

12.36.—Three cheels circling.

12.37.—Many cheels circling.

12.41.—Darker. Thick cloud above and also below me in the valley. Cheels no longer visible, probably settled.

12.44.—Sunshine visible some way down the valley, and cheels there rising and circling.

12.46.—A Lammergeyer seen circling in thin cloud near a patch of sunshine. This was below my level.

12.47.—Sunshine on opposite side of ravine. No cheels up on my side where there was still thin cloud. Four cheels circling down the valley in or near sunshine.

12.50.—Lighter. Cheels circling near, and two vultures gliding.

12.52.—Sunshine. One cheel circling high. Wind imperceptible. Small patches of cloud lying on opposite bank of ravine showed scarcely perceptible movement.

12.55.—Cheels were circling, and white scavengers and vultures were gliding. A Lammergeyer circling and another flex-gliding.

1.0.—Cloud in ravine disappearing. Sunshine and patches of blue sky. The birds had mostly flex-glided away to a distance, or had circled to a level with the tops of the neighbouring hills.

These observations may be briefly summarised as follows. At the beginning of the period of observation, in spite of an ascending current of air (the bottom of the ravine having a rate of ascent of about 1 in 5), the air was not soarable unless there was either sunshine or else a strong glare of light. Towards the end of the observations, as cloud cleared off, the air became sufficiently soarable to permit not only circling but also flex-gliding, although the ascending wind had so far ceased that its movement was imperceptible.

I made a few observations in Naini Tal on the formation of "heat eddies." As in Agra, these could be seen rising from the tops of houses or from the top of a stone wall in sunshine, and also in thin cloud, provided there was a strong glare of light. If the glare diminished from accumulation of cloud overhead, the eddies ceased. Apparently sunlight reflected from a cumulus cloud, or reflected from the snow ranges some 40 or 50 miles away, was not capable of producing heat eddies. Soarability seemed also to need direct action of sun energy. For instance :—

June 27th, 1910.—At Ballia Ravine.—3.22.—Slightly more light. A vulture started and, after gliding about 100 metres, returned and settled. Another started and returned after going about 300 metres. There was thick cloud behind me covering the sun. The glare was mostly by reflection from a cumulus cloud down the valley.

But it is difficult to see how heat eddies can be assumed to be the source of soarability. They only appear to be formed when sunshine (or glare) strikes solid objects. In the presence of strong glare, when birds are circling in thin cloud, not a trace of any eddy movement or anything resembling heat eddies can be seen anywhere near the birds. The thin cloud is usually not homogeneous, but in more or less discrete masses, so that the movement of every cubic foot of air relatively to neighbouring masses of air can be observed. Sometimes the air in the Naini Tal valley is filled with aerial seeds, similar to thistle down (but derived from a tree). These float in the air sometimes almost as thickly as snowflakes in a snowstorm. Their movements serve to indicate the direction of the wind as it flows regularly over the level surface of the lake, or as it is deflected as it meets the sides of the hills. But these aerial seeds show, so far as I have been able to observe, the same irregularity of movement after sunset, when the air is no longer soarable, as they do in the middle of the day when the air can support soaring flight.

On one occasion I was so fortunate as to observe a cheel circling and gaining height when enveloped in thin cloud and in a descending current of air. The cheel was gliding at first in an ascending current of air over the top of Sher-ka Danda Mountain (height 7,520 ft.). It came down the leeward side of the mountain, past where I was standing, at a point 7,400 ft. above sea level, and descended to about 30 ft. below me. The air current was just enough to gently move leaves, and was descending probably at an angle of about 15° with the horizon. The cheel then began circling in this descending current and gained height. On the windward side of one circle it made three flaps. Otherwise, without flapping, it regained a position over the top of Sher-ka Danda, and then glided out of sight. The total gain of height in the descending current of air must have been about 150 ft. During the greater part of its circling the cheel was enveloped in thin cloud, in which, as usual, not a trace of eddy movement was visible. I recorded in my notes that "at the time the cheel was gaining height, it was in cloud sufficiently thin to let through enough sun energy to make heat eddies, judging from the amount of glare at the time, and from the results of observation of heat eddies that I had made two hours previously."

CHAPTER XVI.—Proofs that more Energy is required for Flex-gliding than for Circling.

I have already stated that when, in the evening, soarability decreases, cheels and scavenger vultures are in the habit of collecting at the Agra Fort, and gliding in the ascending current of air over the windward battlements. With a certain strength of wind these birds occasionally glide along the battlements for long distances, keeping uniformly at a height of about 4 ft. or 5 ft. above the parapet. The distance along the battlements from a bastion near to the Delhi Gate to the next is 108 metres. On April 15th and 16th, 1910, I noticed that cheels glided this distance in 13, 14 and 14 secs.; this corresponds to a speed of 7·7 metres per second. Scavengers did the same distance in 11½, 11½, 12 and 12 secs.; this is equal to a speed of 9 metres per second.

On May 11th, 1910, when seated on the Delhi Gate at a point slightly above the level of the battlements, I made the following simple observation, which led to results of some importance :—

5.30.—Cheels noticed that were gliding beam on to the wind, parallel to the battlements, and at a height of 3 ft. or 4 ft. above them. The secondary quills of the leeward wing appeared relaxed—the hinder ends of these feathers, that is to say, were higher than the ends of the feathers of the windward wing. The difference in level was probably 1 centimetre, perhaps as much as 2 centimetres. The birds were gliding on a level keel.

This observation led me to notice the position of the secondaries under different conditions. On the following day I was watching cheels "wind-facing" over the battlements in a light wind Suddenly the wind increased in strength. Immediately the cheels relaxed their secondaries and increased the flexing of their wings—that is to say, instead of ease-gliding they were flex-gliding. Their speed had increased *pari passu* with the increase of speed of the wind, so that they retained their position over the battlements. Hence the peculiar appearance presented by the wings of cheels in flex-gliding is due to the fact that, concomitantly with the decrease in span, there is a relaxation of the secondaries, which, as I shall show later, is equivalent to a decrease in camber in the case of slow flex-gliding. In the case of fast flex-gliding, the camber of the inner part of the wing is not only decreased, but actually abolished. When a cheel is gliding with wings extended, the posterior margin of the wing (formed by the free ends of the secondaries) forms a straight line. When flex-gliding, the posterior margin is no longer a straight line, but forms a curved line with the convexity upwards. In cheels, when flex-gliding, the relaxation affects mostly the more centrally-placed of the secondaries. In vultures, when flex-gliding, all the secondaries appear relaxed to the same extent.

The evidence in my possession goes to show that a particular amount of flexing of the wing and relaxing of the secondaries corresponds to a particular speed. For instance :—

August 28th, 1910.—At 11.40.—A vulture slow flex-gliding with wings slightly flexed, was seen to make a double dip. During the up stroke of this double dip, the wings were seen to acquire extra flexing. This extra flexing was retained, and was followed by an immediate increase of speed.

If, as frequently happens, flexing is increased without a double-dip movement, then the consequent increase of speed is gradual instead of almost instantaneous, as in the above case. That the increase of flexing in such cases is accompanied by increase of relaxation of the secondaries will be proved on a later occasion.

The above facts give a further insight into the nature of flex-gliding. It is now necessary to consider facts that prove that more energy is required for flex-gliding than for circling.

I have observed several instances in which the development of cloud shadow (in Agra), in cases in which the sun is only obscured by a thin layer of cloud, may cause flex-gliding to cease, while permitting birds to continue circling. Though I have only recorded a few such cases, it is probably not an infrequent occurrence. An unaccustomed observer, on seeing circling with gain of height, going on in the absence of sunshine, might infer that cloud shadow has no effect on soaring. I was for some time in this position, and it was only after more lengthy experience that I realised the different effects of thin cloud shadow on circling and flex-gliding.

Examples of decrease of soarability of this nature are as follows :—

March 9th, 1910.—At 12.10.—Wind north. Leaves still. A thin layer of cloud. No birds up except cheels. These were either circling or flex-gliding. No ease-gliding seen except apparently on windward side of fort.

12.30.—Still cloudy. Scavenger vulture seen circling, with occasional flapping.

12.34.—Sunshine.

12.35.—Cheels seen flex-gliding, but with loss of height. No flex-gliding had been seen previously.

March 12th, 1910.—At 3.0.—Thin cloud, but sun making faint shadows. Heat eddies strong. Vultures were flex-gliding and circling.

4.0 to 5.0.—Stronger cloud shadow and heat eddies ceased. Vultures, if at low level, were flap-gliding. If at higher level, they were circling.

July 22nd.—At 8.15.—Cheels near me had been flex-gliding. Shade came over. Then the cheels that were flex-gliding tightened their secondaries, but for a little time continued gliding up wind. Then they ceased such gliding, and confined their movements to circling, or if at low level to flap-circling. A little later flex-gliding at high level was seen.

In this last case, so long as sufficient air energy was available, the cheels were flex-gliding at high speed with secondaries relaxed and with wings strongly flexed. When, owing to the development of cloud shadow, less energy was available, the cheels at first decreased the flexing of their wings and the relaxation of their secondaries, and flex-glided at lower speed. Then, as the available energy continued to diminish, they extended their wings still further, and with a further decrease of speed began circling.

It might be thought that this last observation proves that the bird has some mysterious power of knowing how much air energy is available, and that in consequence it can trim its wings accordingly. Though I have no wish to allow abstract speculation to obtrude on this record of observations, I may briefly state my opinion that the facts now described prove nothing of the kind. For, as will be apparent in later chapters, existing evidence goes to show that the centre of effort of the wings bears a different relation to the centre of gravity according as the bird is or is not taking energy from the air. Thus the only assumption necessary is that the bird is aware when it is losing its balance, and that it can recover or preserve its balance by appropriate adjustments. Some of these adjustments have been already described; others will be described in later chapters.

The following is a case of flex-gliding observed in Naini Tal:—

June 21st, 1910, at 12.57.—A vulture seen flex-gliding up wind at 20 metres per second and at a height of 800 metres above my point of observation. This was on Sherka Danda, at a point 7,400 feet above sea level. After passing over me it glided in and out of thin cloud. Several clouds were near, but the sun was shining. Wind light, occasionally moving leaves.

In Naini Tal, whenever the air had full soarability owing to the presence of bright sunshine, vultures could be seen circling up to a height of several hundred metres above the mountains. When they had thus reached a sufficient height they would flex-glide away, and could sometimes be seen thus gliding for several miles before they went out of sight.

(To be continued.)

AIR EDDIES.

E. V. B. FISHER still manages to retain a happy and more or less contented face, even though the arrival of his new "'bus" has been so long delayed.

However, it should not now be long before the Vickers II is seen at Brooklands, as during the week "E.V.B." is going over to the works at Erith to take charge of the new machine. It is likely that preliminary tests will be carried out at Dartford before it makes its *début* at the Weybridge course.

◆ ◆ ◆

The Rev. Sidney Swann, M.A., who will be remembered as having carried out experiments with a biplane of his own construction at the Aintree Racecourse, near Liverpool, some eighteen months ago, has, since he abandoned the fascinations of flight, distinguished himself in other directions. Just recently he succeeded in lowering the record for rowing the Channel, in a light skiff, from 7 hrs. 15 mins. to 3 hrs. 50 mins. This, for one who has seen fifty summers, is no mean performance.

◆ ◆ ◆

In my opinion, it would be well nigh impossible to find a constructor possessing a more complete grasp of his subject than does Howard Flanders of Brooklands. Indeed the way in which his monoplane carries passengers with the 60-h.p. Green seemingly at half-throttle is sufficient evidence of his worth as a designer. I should have thought that he would have made an attack on the Michelin prize ere now, but apparently he is not yet quite satisfied with its running, as he intends to spend another week or two in adjustments.

Awfully particular chap, Flanders!

◆ ◆ ◆

Henry Farman is nothing if not vigorous as a designer, for he seems to produce new machines on the average of about one a month. His latest product is a biplane of a "Light Military Type." The front elevator and outriggers have been revived, extensions are still fitted, and the number of struts in the *cellule* has been reduced from 16 to 12. Farman has also effected a change in his landing chassis, for it now presents a track of no less than 14 ft., while 4 vertical chassis-struts replace the eight originally employed.

◆ ◆ ◆

It is a peculiarity of the Farman brothers that while Maurice is gradually approaching the "aerobus" in each design he produces, his brother Henry undoubtedly favours the biplane which possesses the lightness, the rapidity, and general handiness of the monoplane. Henry Farman is really not far wrong, for the advantages of an aeroplane from a military point of view are not solely confined to weight-lifting, but include such factors as speed and portability.

In the matter of radius of action there is not much to choose between the two machines, for whereas the Maurice Farman biplane can carry loads of petrol, and keep plodding along, Henry Farman's new machine need carry much less fuel in travelling a similar distance in shorter time. By-the-way, I wonder what has become of the Henry Farman monoplane.

◆ ◆ ◆

Some of our waggish aviators simply cannot give up the awful habit of wagging when they are not flying. While discussing, the other day, the merits and demerits of fostering the growth of mustard and cress on the under surface of aeroplane wings, in order that they may constantly work in the upward "*remous*" caused by the action of the sun on green vegetation, one such person cheerfully volunteered the suggestion of "doping" the wings with a paste made from *self-raising* flour. With such ingenuity the days of the helicopter should not be far ahead.

◆ ◆ ◆

Poor Charles Hubert, who recently suffered injury to the extent of two broken legs in a fall on a Military Farman at Hendon, has been taken from the Central London Sick Asylum to St. Mary's Hospital, Paddington, where he is progressing favourably. On the day after his smash Hubert got busy dictating replies to the many messages of sympathy that he had received.

◆ ◆ ◆

Evidently Grahame-White is determined to embark upon the construction of aeroplanes on a large scale, for in two of his hangars at Hendon he is laying down a fairly complete plant of power-driven wood and metal working machine tools. A third shed is destined to become an erecting shop. Let us hope that he will meet with as much success in his new expansion as has hitherto been his.

◆ ◆ ◆

"There is at least one man who never brags of his descent—the aviator."—*Satire*, New York.

In some cases, perhaps; but there are aviators to be found who are not altogether affected by an acute fit of depression when you ask them to recount the story of a "rather good crack-up," especially if they have been lucky enough to come out of it without personal injury.

◆ ◆ ◆

The new monoplane under construction at the Martin and Handasyde shed at Brooklands is taking an aeroplane-like form and, if all goes well, should be ready for its trials by the end of the month.

◆ ◆ ◆

Frank Champion is still doing well out in Southern California. The other day he flew from Oceanside to his home at Long Beach, a distance of eighty miles in fifty-five minutes.

A newspaper report which he sent me describing this flight is more than usually interesting compared with most of the accounts that are written about cross-country flights. After making the assertion, "Hitching his aeroplane to a post he went in for breakfast," the journalist proceeds to venture the opinion that "aeroplaning, even more so than *automobobiling*, gives the partaker a hearty appetite."

◆ ◆ ◆

Mr. Barber the designer and constructor of the well-known Valkyrie aeroplane, is at present in Paris, he having been approached in several directions, not only in France but in Austria, in connection with establishing constructional works for his particular machine in those countries, and the inducements which are being offered him in this respect are such as to probably incline him to take the matter up seriously. He, like most other British constructors, has received extremely scant official encouragement in this country, and it is hardly surprising therefore that those who are anxious to see the science go forward with greater strides should find an outlet for their work under more encouraging and congenial conditions than at present prevail on British soil. On the Continent, full appreciation is given to the future of the aeroplane and official encouragement with the leading Governments is as conspicuous there as indifference is conspicuous in official quarters in this country.

"OISEAU BLEU."

A Study of Bird Flight

By Dr. E. H. Hankin. M.A. DSc.

CHAPTER XVII.—The Nature of the Problem to be Solved.

It must be obvious that the facts hitherto adduced have led to no explanation of the nature of soarability. But they have shown that there is a problem to be solved, and have given us some idea of its nature. Definite proofs have been brought forward that soaring flight cannot be explained by the assumption that the bird takes advantage of chance currents of air. No reason has been discovered for believing that soaring birds have any mysterious senses or instincts. There is a mystery, but it is one that has to do not so much with the bird as with the source of energy. If we are not dealing with a new form of energy we are at least dealing with a new and hitherto unsuspected method by which sun energy (in the case of sun soarability) can be transformed into mechanical power.

Some time ago a speaker at a learned society stated that he had once seen soaring birds come to rest as soon as a cloud came over the sun. The sun, he said, causes upward currents of air. Therefore soaring flight is due to these currents. Therefore also, man having no power of appreciating these currents can never hope to imitate soaring flight. This line of argument can I think be criticised on three grounds. Firstly, it is a case of using one unknown to explain another unknown. Secondly, it is generalising on a single experience. Thirdly, it concludes with a rash prophecy that at least is out of place in a scientific argument. The question of the nature of soarability requires and deserves more serious treatment. There is very little probability of its nature ever being cleared up by any single and sensational discovery. All we can hope for is that our knowledge of soarability may be advanced by observation and measurement. It will be of interest to indicate briefly what lines of research seem likely to add to our knowledge of the subject.

As I have elsewhere stated (Chapter XII), it is impossible to imagine how a bird can take energy from soarable air if such air is homogeneous, unless such air is altered by the passage of the bird's wing. Hence there are two possibilities to be considered.

Firstly, it is possible that soarable air is heterogeneous, that is to say, that certain parts have movement relatively to other parts. In other words, it is possible that the energy supply is due to the bird acquiring the movement of eddies. As already explained such eddies must be minute in size and uniformly distributed.

The rising of small masses of air under the influence of sunshine I have elsewhere referred to as "heat eddies." Heat eddies, as a rule, commence a few minutes before the air becomes soarable, and gather strength as soarability increases. Hence it is necessary to consider the possibility that heat eddies are the source of soarability. Perhaps, and indeed probably, these heat eddies can lift a piece ot gossamer. They certainly cannot lift a feather. Whether or not they can support a bird of 5 kilogs. weight, and lift it within a few minutes to a height of 1,000 metres, is a question that requires to be settled by evidence. I propose to devote a couple of chapters to facts relevant to this matter.

Secondly, if every attempt should fail to prove that soarability is due to the movement of small masses of air, the second possibility must be considered, namely, that the air is altered by the passage of the bird's wing. It is conceivable that soarable air contains unstable groups of molecules or some unstable chemical compound that can decompose explosively by the passage of a vulture's wing, and so furnish energy for soaring flight. This possibility can be tested by the following method. An explosion of gaseous matter is likely to exert its energy perpendicularly to a flat surface. In fast flex-gliding the wing is flat. Hence, if in this form of flight energy is derived from a sort of continuous explosion, one might expect to find evidence that the force of soarability is exerted at right angles (or nearly so) to the surface of the wing. In other words, one might expect the angle of incidence to be in the neighbourhood of 90°. Hence it is necessary, firstly, to discover the relation of the centre of gravity to the area of the wing in ordinary gliding flight in which the angle of incidence is small. Secondly, it is necessary to discover what this relation is in cases in which the angle of incidence approaches 90°. Thirdly, it is necessary to see whether the relation in this second case bears any resemblance to the relation that obtains in flex-gliding flight. I shall bring forward evidence relating to this matter.

Lastly, it is possible that something may be learnt by comparing the disposition of the wings when the bird is soaring with the disposition employed when the bird is no longer taking energy from the air. From this point of view it will be of interest to study in detail the different modes of descent employed by soaring birds. Chapter XXIII will be devoted to this matter.

I take this opportunity of expressing my thanks to the Advisory Committee for Aeronautics for having kindly given me information on certain points that I submitted to them.

CHAPTER XVIII.—Wing Depression.

In an earlier chapter I described two kinds of movements that are used by birds for steering in the horizontal plane. The first is the "dip," which has been shown to be due to a rotation of the wing tip. The second movement is the "depression." The question arises whether the depression observed is an actual depression of the whole wing caused by direct muscular action, or whether it is due to a rotation of the wing, and the resulting depressing effect of the air striking its upper surface.

That the depression is a movement of the same nature as the dip, namely a rotation, is indicated by the following facts. Firstly, in the case of cheels the two modes of steering are usually combined. If a cheel is gliding with wings extended, steering may occur by a wing depression, or by a depression combined with a dip. I have no clear recollection of seeing a dip movement in a cheel without there being at the same time some appearance of depression of the whole wing.

Secondly, where, as in the case of vultures, the two kinds of steering movements are usually distinct, one or the other may occur apparently under the same conditions. For instance :—

June 12th, 1910.—At Ballia Ravine, 12.6.—A vulture started from a tree near me and glided in a nearly straight line for about two miles. During the first part of this glide, two steering movements were seen, one a dip, and the other a depression of the whole wing. The latter produced the stronger change of course.

Thirdly, in the case of the double dip movement, it is often difficult to see how far it is due to a movement of the wing-tip and how far to a depression of the whole wing. Only after my arrival in Naini Tal did I have opportunities of making observations with definite results, as shown by the following evidence :—

June 19th, 1910.—Ballia Ravine. At 12.30.—Sun shining. A brown vulture while ease gliding down the valley showed a momentary depression of both wing-tips, presumably for the purpose of increasing speed.

A lammergeyer seen making a double dip. This was clearly seen to be due to a depression of the whole wing, and not merely of the wing-tips.

June 21st, 1910.—Ballia Ravine. At 3.23.—A lammergeyer seen to make a double dip twice over at short intervals. These dips appeared clearly as a bending down of the wing at the carpal joint. At the time the vulture was gliding downwards at speed. The alulae were not extended. Then it again made a double dip, which was as clearly seen to be not at the carpal joint but at the shoulder joint. A minute later it made another double dip, which appeared to affect both shoulder and carpal joints.

Hence double dips may be seen, either as a dip of the wing-tips caused by rotation of the phalangeal quills, or as a dip at the carpal joint certainly due to rotation of the outer part of the wing, or as a dip of the whole wing in which rotation may also play a part.

I also attempted to settle the matter by direct observation. I will give my records in full, as it is interesting to see how much practice was required before I could make this somewhat difficult observation. My notes include various surmises, of no value except as showing that I was uninfluenced by any particular preconceived idea while carrying out the observations. My diary extracts are as follows :—

July 18th, 1910.—Agra, at 6.40 a.m.—Four cheels up near. They were circling at low level with occasional flaps. Steering was by whole wing depression. During the depression the wing, when seen from behind, looked thicker than it does in gliding flight.

July 24th, 1910.—At 9.47 a.m.—A cheel gliding up wind. It gave the impression that on dipping the whole wing the secondaries (that is to say the hinder or free ends of the secondaries) went up. Also in several other cases the depression seemed to be accompanied by an appearance of thickening. This suggests that the depression is caused by a rotation of the wing.

July 27th, 1910.—At 5.20 p.m.—A cheel during a wing depression showed relaxation of secondaries. Perhaps this was due to a twisting of the wing.

August 5th, 1910.—At 7.4 a.m.—A cheel wind-facing made a

whole wing depression. This gave the same impression as the movement of one of the wings in a double dip.

At 7.24.—A cheel making a whole wing depression showed slight movement upwards of secondaries, while at the same time the wing tip went downwards as in a dip movement. Does a whole wing depression mean a slight arching of the wing, which would involve less efficiency, and, therefore, a steering effect?

August 14th, 1910.—At Futteypur, 8.45 a.m.—An eagle seen gliding up wind. Twice a whole wing depression was seen clearly to be accompanied by a rising of the free or hinder ends of the secondaries. Because the wing depression is not accompanied by any increase of flexing, therefore the wing depression must be due to a twisting of the whole wing. (Facts to be described in a later chapter will make clear the meaning of this argument.)

August 16th, 7 a.m.—A cheel while gliding showed an elevation of the free ends of the secondaries, that is to say, rotation of the wing, which was seen to be followed by depression. I was very astonished at being able to see this.

This last observation was quite unexpected. Though I have no doubt that it represents accurately what actually happens in a wing depression, I am inclined to think that it was of the nature of an accident that the rotation of the wing was presented to my consciousness as a phenomenon preceding the depression. Since making this observation I have frequently been able to see that in a wing depression the front edge of the wing is depressed and the hind edge is slightly elevated. There can, therefore, be no doubt that the movement consists in a rotation of the wing, and that the depression ensues when the wing is no longer supported as before by the air pressure from below.

The above observations, therefore, point to the conclusion that birds may steer in the horizontal plane, either by rotation of the wing tip or by rotation of the whole wing.

It is necessary to consider possible criticisms of this conclusion.

1. When describing the flapping and other movements connected with perching, I shall show that the wing, when in use, can be

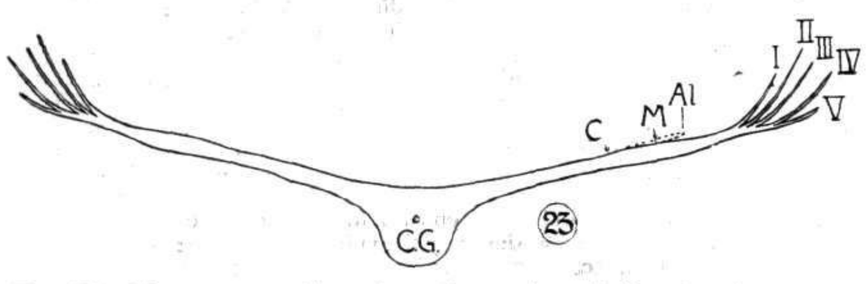


Fig. 23.—Transverse section of a vulture when circling in fully soarable air. CG, position of centre of gravity. C, carpal joint. M, metacarpal joint. Al, position of alula, shown by dotted line. I, II, III, and IV, tips of phalangeal quills pressed upwards by pressure of the air. V, position of metacarpal quill tips.

rotated through an angle of nearly 90 degrees. There is, therefore, independent evidence of wing rotation.

2. That the movement observed cannot be due to relaxation of the secondaries of the depressed wing, that is to say, to a diminution of camber, will be shown when I come to describe the mechanism for altering camber in a later chapter.

3. That the rotation of the wing, or of the wing tip, for steering in the horizontal plane is not accompanied by a rotation of the other wing, or of the other wing tip in the opposite direction, will shortly be proved.

4. In a later chapter I shall have to describe cases in which a slight relaxation of the secondaries of the outside wing may possibly play some part in steering.

5. I hope on a later occasion to describe my observations on the conditions under which tailless cheels are unstable. It will be seen that the facts observed lead to the conclusion that movements of the tail do not produce steering effects.

6. Cheels may on rare occasions show sudden rotation round the dorso-ventral axis through as much as 90°, or even a larger angle. I shall describe these rotations in Chapter XXXIII, and shall show that they have nothing in common with ordinary steering movements.

CHAPTER XIX.—Canting.

Warping of the wings of an aeroplane to equal amounts in opposite directions may conveniently be referred to as "Wright's method."

There is a certain resemblance between the warping of the wing of an aeroplane and the rotation of the wing-tip found in birds. One would therefore expect that birds use Wright's method for preserving lateral stability, or, as it may otherwise be expressed, for producing or checking rotation round the longitudinal axis.

But I am acquainted with no evidence that Wright's method is used by birds. That is to say, during a dip movement of one wing, there is no evidence of any upward rotation of the front edge of the wing-tip of the other wing. At the time that I made the following observation, I thought that I had found an instance of the use of Wright's method :—

June 30, 1910.—Ballia Ravine. 2.30.—High level clouds only. A few vultures perched, and one in sight in the air. Slight sunshine. A lammergeyer seen circling near. The first quill feather of the outside wing was turned up while the bird faced the wind, but not when the bird was travelling with the wind. The gradual return of the end of the feather to the horizontal position was clearly seen as the bird turned in each of several successive circles. The wind at the time was nearly imperceptible, but occasionally moving leaves slightly.

Further experience has shown that the above observation cannot be regarded as an instance of the use of Wright's method. The return of the first quill feather to the horizontal position, mentioned in the above extract, was not its return to the normal position. On the other hand, as shown in Fig. 23, the tips of the phalangeal quills, when circling, are normally turned upwards. The first quill, in the above instance, assuming the horizontal position was of the nature of a half dip movement, as will be further described and explained in a later chapter. The range of movement observed in this instance of the first quill feather was probably less than two inches. The bird was probably of nine feet span or more.

That canting in soarable air is not merely a consequence of travelling on a curved course with the centre of gravity below the centre of effort of the wings is shown, firstly, by the facts of canted flex-gliding. In this form of flight, as elsewhere described, the bird is canted though travelling in a straight line. Secondly, a similar conclusion can be drawn from the phenomena shown in circling where the amount of canting is inversely proportional to the speed.

Parrots and pigeons in fast flapping flight on a curved course are always canted. I have seen an adjutant bird become canted while flapping and then cease flapping and begin circling. This observation makes it improbable that the canting was produced by any movement of rotation either of the wing or of the wing tips, as will be apparent when I come to describe the facts of flapping flight.

In a later chapter, when describing "dropping turns," I shall mention cases in which canting is produced by momentary increase of flexing of one wing. This acts simply by decreasing the supporting area of the wing, which, therefore, drops a short distance through the air, producing the canted position. In Chapter XXI, I shall describe cases in which canting is produced or removed by "arching" of one wing.

Of the different methods used by birds for meeting a puff of wind, the following method, that may be described as "wind-canting," is of interest. Supposing a cheel is ease-gliding to windward against a strong wind. As it gradually glides into an ascending current of air reflected upwards from a tree or building, it is obvious that at a particular moment when the front part of the wing is more affected by the ascending air than the back part, there must be a tendency for the bird to be rotated upwards round its transverse axis. That is to say, it must tend to rotate round this axis in such a way that the beak tends to go up and the tail tends to go down. As this occurs (or appears to occur), the cheel may be seen to rotate itself on its dorso-ventral axis through about 90°. The consequence is that the bird avoids being tipped up round its transverse axis. That is to say, its angle of incidence by this simple manœuvre has been kept normal. But the bird has become canted, and is now gliding in a direction at right angles to the wind. Sometimes a dip movement of the leeward wing may be seen, and the bird then gradually turns off and glides away to leeward. While thus gliding away to leeward it loses its canted position and returns gradually to a level keel. I have seen a similar method of dealing with a puff of wind in "storm soarability" in cases in which there was no evidence of any upward current. In such cases of storm soarability I have occasionally seen the bird make steering movements of such a nature as would tend to check the rotation round the dorso-ventral axis.* It is therefore doubtful whether the rotation round the dorso-ventral axis is due to any action on the part of the bird. Further light will be thrown on this point by the facts to be described in the next chapter.

* Instead of turning off from a puff of wind, a bird may cope with it by adopting the disposition for increased speed. That is to say, it remains facing the wind, but elevates the furled tail, places the wings dihedrally down, increases their flexure, and relaxes the secondaries, that is to say, decreases the camber. On two occasions, in addition, I have seen momentary lowering of the legs, but I am not sure whether this movement had to do with meeting a squall.

(To be continued.)

A Study of Bird Flight

By Dr. E. H. Hankin, M.A. DSc.

CHAPTER XX.—Lift-gliding of Black Vultures, and Remarks on Lateral Stability.

The following is an instance of a rarely observed phenomenon, namely, an appearance of lateral instability :—

February 6th, 1910.—At 2.9.—A very strong north wind blowing. Much dust in the air, but sun shining. Some cheels flex-gliding at very little height (2 or 3 feet) over the tree-tops. (This, as will be explained later, is evidence of "storm soarability.")

2.45.—There was a lull in the wind, but it had not died down completely. A black vulture was seen flex-gliding nearly directly to leeward at a height of less than 50 metres. It passed me (I was on the roof of my house) at about a hundred metres distance. While it was passing the wind suddenly freshened. The black vulture at once commenced leeward looping. It proceeded thus for about half a mile to leeward. It then began gliding up wind, nearly in my direction, at a height of less than 100 metres. Its wings were dihedrally up. During this lift glide it showed both lateral and dorso-ventral axis instability. As soon as it had advanced a little to windward of my position, it began circling. Instantly the instability vanished. As it circled, it drifted to leeward, showing in each circle a clearly marked gain of height.

It will be worth while to describe in detail the two kinds of instability shown by this bird. The tendency to rotate to and fro round the dorso-ventral axis could clearly be seen to be associated with gain of height. Whenever the bird, instead of proceeding horizontally, began to glide in an upward direction (at a small angle with the horizon), one wing always appeared to gain more height than the other. Hence the bird always became canted over, and then glided off its course for two or three metres to the right or left. It was as if the bird every now and then was climbing a greasy pole inclined at an angle of 20° or 30° with the horizon, and as if it kept slipping off to one side or the other.

This tendency to swerve off its course to one side or the other is always seen in lift-gliding by every species of bird that I have seen in this form of flight. If a bird is gaining height in soarable air there is always this tendency to travel on a curved course. There can be little doubt that this fact is the reason why circling is usually adopted for purposes of gain of height.

The second kind of instability shown by the black vulture in question was a tendency to rotate to and fro round the longitudinal axis. Every now and then, while the bird was moving horizontally, one wing was seen to move downwards for a short distance, while the other wing moved upwards to the same extent. The range of movement of the tips of the wing was two or three inches. The wings appeared to be held perfectly stiffly. No effort to check this tipping could be observed.

The first idea that occurred to me was that this was a case of lateral instability, and that the bird used some adjustment that I was unable to detect in order to check this tendency to rotate round its longitudinal axis. Further experience has shown that another explanation is more probable. Longitudinal axis instability of black vultures is most commonly observed late in the afternoon. Rarely it may be seen in the morning, but then only in cases in which the weather is disturbed, and when it is, therefore, probable that the soarability of the air is not uniform and is of low degree.

It was only after a year's acquaintance with the subject that I met with a case of longitudinal axis instability in a common vulture. In this case the vulture was at a low level, and the time was late in the afternoon. I have since seen another instance.

The reason why this form of instability is met with comparatively frequently in black vultures and so rarely in common vultures is, I think, to be found in the fact that the black vulture habitually soars at a lower level than the common vulture. During the afternoon, as the power of the sun decreases, the air near the earth gradually loses its soarability. The black vulture, owing to its habit of gliding at low levels, is apt to get into patches of unsoarable air. The form of instability in question is more frequently seen in flap gliding than in ease-gliding or circling. The flapping gives an additional proof that the air is not of a sufficient degree of soarability. If soarability is not uniform but occurring in patches, one may expect one wing occasionally to be better supported than the other, with a resulting appearance of lateral instability. Supposing the speed of the black vulture was known, then by counting the number of oscillations that occur in a given time some estimate could be made of the size of these patches of less soarable air.

In the morning large areas, perhaps a square mile or more or less, may acquire soarability a few minutes before neighbouring areas. But the facts now described suggest that when soarability is decreasing the loss occurs in patches which may be only a few metres in diameter.

I may close this chapter by a few remarks on the question of lateral stability.

By the study of movements of extreme degree round the transverse axis it was possible to discover the nature of the adjustment by which such movements are produced, that is to say, of the adjustment by which the bird is able to maintain its longitudinal stability. That this adjustment is actually in frequent use by cheels is a matter of observation. It may be inferred that it may be in use in other cases to an amount too small to be detected by observation. What degree of automatic longitudinal stability the bird possesses is not settled by my observations. All that can be positively affirmed is that it is not sufficient for all occasions.*

Similarly with the question of lateral stability, it is not likely that the adjustment concerned in maintaining lateral stability will be discovered by observation of birds in normal flight. One may reasonably expect it to be necessary to study cases of oscillation round the longitudinal axis of unusual degree. Of such cases, the extreme degree of canting sometimes observed in circling is not suitable for observation. The bird acquires the canted position so gradually, and returns to a more or less level keel also so gradually, that if the movement is due to an adjustment, this adjustment must come into action so gently that there must be little chance of its coming under observation. The case just described of sudden oscillations round the longitudinal axis of the black vulture is, as has been shown, probably due to atmospheric irregularity, and no trace of any adjustment causing it can be seen. But another case of oscillation round this axis is known to me. Cheels when swooping steeply downwards sometimes show oscillations of large extent round the longitudinal axis. A study of the conditions under which these oscillations occur will be found to give some clue to the probable nature of the adjustment used for maintaining lateral stability. Unfortunately, this case must be described in a later chapter, as the facts will not be intelligible until I have described flapping flight and certain other subjects.

CHAPTER XXI.—Arching.

Concavity of the bird's wing in the fore and aft direction is known as camber. Concavity in the lateral direction, that is called "arching." I have already used the term "flat" to describe the position of the wings when they are in the same straight line with one another, that is to say when there is no dihedral angle. I therefore propose to describe a single wing as "even," if, when seen from behind, it lies in one plane and shows no arching.

The wings of the cheel when ease-gliding are sometimes arched and sometimes even. I have not observed the arched position in cheels during the monsoon season, nor in very cold weather.

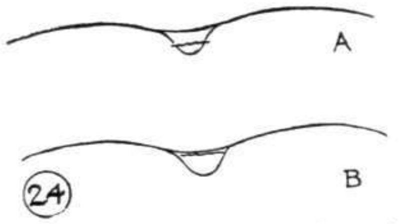
Certain facts suggest that the even position of the wings is that of greatest efficiency for obtaining energy from the air. Very often, perhaps more often than not, in the case of cheels, it is difficult to say whether the wings are arched or even, as one is generally not in a sufficiently good position for observing.

On one occasion at Jharna Nullah, in April, 1910, I noticed that before the air became soarable, cheels in flap-gliding flight held their wings in a slightly arched position during the periods of gliding. When circling commenced the wings were held completely even, either flat or perhaps occasionally slightly dihedrally down. Within a minute the wings, still even, could be seen occasionally to assume the dihedrally up position. About two minutes later ease-circling had commenced, and the wings were frequently seen to be strongly arched.

* As by practice my powers of observation have increased, I have been able to see tail-jolting more frequently. In extreme cases each upward jolt of the tail is accompanied by a slight relaxation of the secondary quills (an adjustment for speed), and the wings are placed slightly dihedrally downward. In other cases only very minute up and down movements of the tail can be observed. I have only seen tail-jolting three times in vultures. The smallness of the tail of the vulture and the height at which they soar are probable reasons why tail-jolting is not more often seen in these birds. I have never seen tail jolting in flapping flight.

On only one or two occasions have I been able to see arching of the wings of vultures in Agra. At Ballia Ravine, in Naini Tal, on the other hand, perhaps owing to better opportunities of observation, I was able frequently to see it, both in the case of the common (white-backed) and in the case of the brown vulture. The appearance in these two species of vulture is shown diagrammatically in Fig. 24.

These vultures when starting usually glided horizontally for some way down the valley, on the rising current of air, with their wings



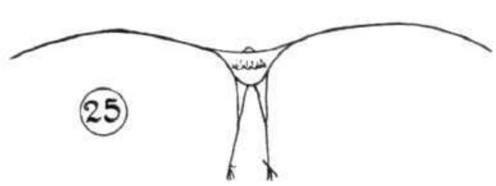


Fig. 24.—Diagrammatic end-on view, showing arching in vultures: A, of common or white-backed vulture (*Gyps bengalensis*); B, of brown vulture (probably *Gyps indicus*). A has a tail at a lower level than the wings.

Fig. 25.—Adjutant seen from behind, with wings arched and legs hanging down.

arched. After travelling for several hundred metres in this way, it was a common observation to see the wings suddenly assume the dihedrally up position, and to become even. This change was at once followed by a gain of height, after which the bird commenced circling.

An observation of arching in a vulture in Agra is as follows:—

August 2nd, 1910, at 4.—A brown vulture seen circling downwards from a height of, perhaps, 800 metres to a height of, perhaps, 400 metres. After this descent it ease-glided horizontally with wings arched. Then it turned slightly in its course, and while still travelling horizontally, its speed was seen to increase. It was then seen to be flex-gliding. I did not observe a double dip at the commencement of this change to flex-gliding, and doubt whether such movement occurred.

Observations that I have carried out on adjutant birds and flying foxes show definitely that arching involves a decrease of lifting efficiency in these animals. It will he sufficient for my present purpose to quote in detail my observations on adjutants.

CHAPTER XXII.—Adjutant Birds.

The adjutant bird is a species of stork of large size. One that I had in captivity for a few months measured nearly 11 ft. across the wings. It is a temporary resident in India, arriving in April or May, and usually departing in October. A few individuals, however, remain during the cold weather months.

Two adjutants that I shot had the following measurements:—

A		B	
Span	9 ft.	Span	9 ft. 2 ins.
Width of wing ...	1 ft. 3 ins.	Area of one wing ...	4·85 sq. ft.
Length of wing ...	4 ft.	Area of wing tip ...	1·85 ,,
Weight 7,344 grammes = 16·86 lbs.		Area of phalangeal quill mass	·71 ,,
Area of both wings ...	10·5 sq. ft.	Area of one secondary quill	·166 ,,
Loading per sq. ft. of wing area	1·54 lbs.	Area of one secondary quill not overlapped by its neighbour (*i.e.*, exposed directly to air pressure) ...	·105 ,,

In most respects the flight of adjutants resembles that of vultures. They circle with vultures, and may be seen flex-gliding. In the flex-gliding position the wings are usually not quite so much flexed as in the case of vultures, but the difference between the circling and the flex-gliding disposition of the wings is quite easy to recognise.

But their flight differs from that of vultures in the use they make of arching. Arching the wings in the case of a vulture merely seems to result in decrease of efficiency. In the case of the heavier adjutant, arching the wings results in immediate descent. Arching is the method of descent employed by adjutants in a strong wind or when for any reason they are in a hurry. If an adjutant is watched gliding horizontally, its wings will be seen to be even and set at a slight dihedrally up angle. If it then places its wings in the arched position it immediately begins to glide downwards. Increasing the amount of arching hastens the rate of descent. If when gliding with wings even, one wing is momentarily arched, that wing descends, giving the bird a canted position. If an adjutant is already canted, then momentary arching of the upper wing will cause it to come to an even keel.

The following are examples of my observations:—

July 18th, 1910.—At 5.13. Jharna Nullah.—An adjutant after flex-gliding at 200 metres height began descending almost vertically. Its wings were arched, secondaries tight, and legs half dropped. This was in a strong wind. When about two metres from the ground the arching increased. Another adjutant alighting in a sheltered place showed "stop-flapping" but no arching.

July 20th, 1910.—At 5.52.—An adjutant gliding with wings slightly flexed slowly descended to about 80 metres height. Then it dropped suddenly, frightening away a cheel. Probably it was attracted by carrion that the cheel was eating. The adjutant commenced the drop with a strongly marked double dip. This resulted in steep but momentary inclination of the body (*i.e.*, rotation downwards round transverse axis). Immediately after this inclination its wings were seen to be strongly arched. The legs were hanging down. The head was raised above the level of the wings instead of being below their level as in ordinary gliding flight. This movement of the head may have been preparatory to striking or threatening the cheel. The wind at the time was light.

That the above surmise, as to raising the head, is not correct, is shown by the following observation:—

August 14, 1910.—At Futteypur-Sikri. At 1.15.—A bird, probably an adjutant, perhaps a crane, descending from about 700 metres to perhaps 400 metres height, showed arching and head raised during part of its descent, besides legs being partly dropped. The bird then drew up its legs and flex-glided away.

It is obvious that raising the head must affect the position of the centre of gravity, and possibly the object of this movement is to produce some change in the position of the centre of gravity.

The amount of arching shown by adjutants in descending is greater than I have observed in ease-gliding vultures. The appearance in end on view of an adjutant with wings arched is shown diagrammatically in Fig. 25.

Steering in the horizontal plane when the wings are arched is effected by what is apparently a dip movement of the inside wing. There is an appearance of the wing-tip being twisted, but the result resembles an increase of arching.

The following is an example of momentary arching of the upper wing being used by a vulture to remove canting:—

August 30, 1910.—At Jharna Nullah. 5.10.—Clouding over. All adjutants settled and vultures descending. A vulture gliding downwards in a canted position arched its upper wing momentarily. Thereupon the amount of canting greatly decreased. The movement observed must have been arching, and not a wing depression, because as the bird diminished its canting, it turned and glided off to the left. Had the movement been a depression the turn would have been to the right.

The question arises, what is the nature of arching? I have a rough acquaintance with the direct or immediate action of all the intrinsic muscles of the wing of an adjutant. I am therefore able to assert that there is no muscular mechanism capable of producing the arched position by any direct action. The facts concerning arching are, firstly, that the wings make a dihedrally up angle with the body, and, secondly, when arched, the air does not impinge on the under surface of the phalangeal quills. That is to say, in the arched position the wing tip has been rotated. Rotation of the wing tip only, when the wings are dihedrally up, would merely produce an appearance of a dip of the wing tips, as I have had occasion of observing. Hence it appears probable that arching is produced by slight rotation of the whole wing while it is in the dihedrally up position. In other words it is probable that arching is a position in which the angle of incidence of the wing is diminished. In later chapters I shall describe other modes of descent in which there is also a change from the normal angle of incidence.

In the case of the flying fox there is a muscle which by direct action can produce arching by bending downwards at the carpal joint. A few observations have led me to suspect that in this animal also there is a decrease in the angle of incidence in the arched position.

(*To be continued*).

A Superior Military Certificate Obtained on an Antoinette.

FOR the first time a French officer, Lieut. Rochette, has secured the superior military *brevet* on an Antoinette monoplane. On the 28th ult. he covered, for his third flight, the course between Mourmelon and Revigny, 104 kiloms., at a height of 500 metres.

A Study of Bird Flight

By Dr. E. H. Hankin, M.A. DSc.

CHAPTER XXIII.—Descending of Vultures at Ballia Ravine.

THAT a bird should flex its wings and glide downwards with speed increasing under the influence of gravity is what one might expect to happen, and I have already quoted examples of such an occurrence.

That a bird flexing its wings to a lesser degree should glide downwards at an angle of about 10° or 15° with the horizon, with speed continually decreasing, in spite of the action of gravity, is not what one would expect to happen. I therefore thought that it would be worth while to devote attention to this phenomenon, for which I had exceptionally good opportunities during my stay in Naini Tal. It will be seen that the attempt to explain this decrease of speed will involve an advance in our knowledge of gliding flight.

Vultures returning to roost on the trees in Ballia Ravine could be seen circling near the top of the end of Sher-ka Danda mountain, and then gradually circling downwards in a large spiral. When they commenced this descent, they placed their wings in a slightly flexed position, and glided downwards in circles of decreasing diameter and at a diminishing speed. The vertical distance through which they circled before reaching their roosting place was between 350 and 400 metres. They usually took from 60 to 80 seconds to make this descent.

On a day on which vultures had been flex-gliding at 18 to 24 metres per second, I noticed one circling downwards at 12 metres per second. When it had reached a lower level, I estimated its speed again, and found it to be 8 metres per second (June 21st, 1910). Another vulture, when circling down but still near the top of Sher-ka Danda, was found to be travelling at 12 metres per second. On different occasions I found the following values for the speeds of vultures circling downwards near the end of their descent: 9, 6, 6, 6, 8, and 8 metres per second.

Usually, but not always, when circling downwards, the feet were hanging down. As the bird neared the perch, first its legs and then the legs and body were allowed to hang down below the level of the wings. The alulae were either not extended at all, or if they were extended this only happened a short time before perching. In the case of a Lammergeyer (on June 21st, 1910), I have, on one occasion, seen both alulae extended and rotated upwards during the whole of several successive circles during descent. Occasionally, besides the feet, the legs were also partly hung down while the vulture was at some distance from the perch.

Vultures thus descending with loss of speed steered by dip movements. A double dip was also once observed.

A vulture descending with legs hanging down was once seen to be struck by a puff of wind. It responded by momentarily increasing the flexure of both wings.

Of the different adjustments that may be supposed to act as brakes in decreasing speed, it will be obvious from the above brief description that extension of the alulae or hanging down of the legs or feet must be of subordinate importance and need not here be further considered. A peculiar kind of flapping that occurs just before perching will be described in a later chapter under the name of "stop flapping." It will be shown that this acts as a brake.

My observations soon showed me that during descent with loss of speed the camber was maintained at its maxim instead of being decreased as it is in ordinary flex-gliding flight. I propose first to attempt to prove the correctness of this observation, and then, after explaining the mechanism for altering camber, to bring forward reasons for believing that in descent with loss of speed there is an adjustment that tends to put out of action the lifting and tractive power of the cambered wing. There can be little doubt that in this adjustment it is the brake that is of importance in decreasing speed.

First, by way of proving the correctness of my observation of maintenance of camber in descent, I may refer to my description of the descent of vultures at Futteyeur-Sikri (Chapter IX). I stated that towards the end of their descent the vultures exhibited a swaying from side to side to which I gave the name of "parachuting." The track of a bird when parachuting is shown, as seen from in front, in the accompanying Fig. 26. At each angle of the zigzag, the bird makes a "dropping turn." Somewhat suddenly its cant in one direction is changed to a cant in the opposite direction. While making this change the bird continues to face almost or quite in the same direction. There may, in some cases, however, be a slight rotation round the dorso-ventrol axis during the turn.

As, during these dropping turns, the centre of gravity is far below the centre of effort of the wings, I was under the impression that the bird was oscillating from side to side like a pendulum, and that any tendency to oscillate in a fore and aft direction was quenched in some way that tended to cause the bird to lose height and speed.

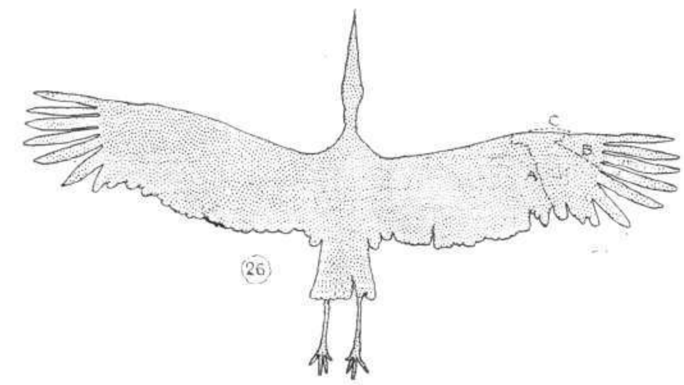


Fig. 26.—Adjutant circling. The dotted line, A, indicates junction of secondary and metacarpal quills. The line, B, indicates junction of metacarpal and phalangeal quills. C is outline of alula.

My observations at Ballia Ravine, however, showed me that this movement was not automatic (in the sense of being due to a pendulum-like oscillation), but that it was voluntary and due to an adjustment that I was fortunately able to discover. After watching a number of vultures descending one after the other and each making a dropping turn at about the same position, at first I saw that there was some displacement or movement of the secondaries of the wing that became lower at the moment of the dropping turn. Then, as I became more practised in making the observation, I formed the impression that, at the moment of turn, there was a temporary increase of flexing of the inside wing. Lastly, I was able to see with certainty that this sudden and temporary extra flexing occurred, and that it was accompanied by a momentary relaxation of the secondaries. That is to say, a dropping turn is an example of a bird becoming canted by decrease in supporting area of the wing that thereupon becomes lower in position.

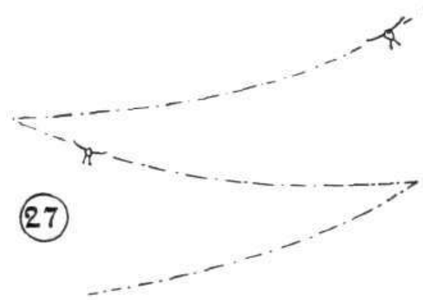


Fig. 27.—Track of a vulture when "parachuting," seen from in front. At each angle of the zigzag the bird makes a dropping turn. That is to say, having been canted in one direction the upper wing descends, so that it becomes canted in the opposite direction.

The import of this observation of the slackening of the secondaries during the dropping turn, is that it proves the correctness of my observation that the secondaries were not relaxed while a dropping turn was not taking place. That is to say, during descent with loss of speed secondaries were kept tight.

Owing to the fact that at Ballia Ravine I was on the same level as the birds under observation, I was able on a few other occasions to observe relaxation of the secondaries. The details of these very difficult observations are as follows:—

June 17th, 1910. At 2.34.—A vulture circling, in air blowing up the valley, was seen to relax the secondaries of the outside wing on the leeward side of the circle.

9.43.—A vulture, to avoid another, was seen to dive by double dip and momentary relation of the secondaries.

June 21st, 1910. At 2.35.—A vulture turning showed slight relaxation of secondaries of outside wing.

June 25th, 1910 At 12.35.—A vulture turning in thin cloud near seen to slacken secondaries of outside wing.

June 26th, 1910. At 11.36.—Two vultures ease-gliding, and then commencing to descend. I formed the impression that the tightening of the inside wing secondaries occurred while turning. After the turn (which was a turn in the horizontal plane), the secondaries of both wings were tightened. (That is to say, the wings were adjusted for descent by increase of camber to maximum.)

Two vultures descending showed a double dip, accompanied by increased flexing of wings. In each case, at the time of increased flexing, a relaxation of secondaries was seen.

What I have described in the above diary extracts as "relaxation of secondaries" was a moving upwards of the posterior margin of the inner or cambered part of the wing. The movement cannot in any case have been as much as an inch in birds of 7 or 8 ft. span. These observations, therefore, were difficult to make, and at the time entirely unexpected. It will be seen that they refer to two kinds of relaxation; one, quite momentary, coincident with a momentary but visible increase of flexing, the other lasting perhaps for several seconds, in which no increase of flexing was observed. That in this latter case a slight increase of flexing must have occurred, will be shown in the sequel. It will also be shown that, in each case, the relaxation of the secondaries was equivalent in a decrease of camber, and was a disposition for increase of speed.

We have now to consider more closely the nature of the wing-flexing shown by the descending vulture. When taking their time of descent with a stop-watch, I soon learnt to distinguish at a glance between a descending and a flex-gliding bird. There was some difference in the appearance of the flexed wing in the two cases, but not a difference that I could grasp sufficiently to express in words.

It will facilitate description if I mention two theories that I formed to account for the appearance of the descending bird.

Firstly, it occurred to me that possibly in fast flex-gliding the flexure is more at the elbow joint, while in descending possibly the flexure was more at the carpal joint. It was conceivable that the ligaments of the wing should be so arranged that one kind of flexing would affect camber and the other have no effect on camber.

Secondly, the idea occurred to me that the maintenance of camber in the descending vulture might be due to direct muscular action. I had some recollection of a muscle that I had found in the wing of a vulture that appeared to be capable of producing this adjustment.

After my return to Agra I put these theories to the test by dissection of an adjutant bird of nine feet span, and later on of a vulture of seven feet span.

Firstly, with regard to the idea that change of camber may be due to muscular action, as I expected I found a muscle that originates on the lower end of the humerus. Its tendon does not run straight, but follows a somewhat curved course with its convexity backwards. This tendon is inserted into the lower end of the ulna. As shown in Fig. 28, extensions from this tendon go to the membrane that binds together the bases of the outer secondary quills. The result of this arrangement is that, on pulling the muscle, its main tendon becomes straightened. There is, therefore, a pull on the extensions. The outer secondaries are thereby drawn downwards and also inwards towards the body of the bird. This displacement of the secondaries is in effect an increase of camber, but the action is slight. It cannot therefore be denied that the action of this muscle may have to do with the maintenance of camber. But its possible action does not seem proportionate to the effect actually observed, and it appears more probable that the chief function of this muscle is of a less important nature, such as arranging the feathers on furling the wing.

Secondly, I investigated the relation between change of camber and change of flexing. On holding the wing loose in the hand and extending and flexing the different joints, no certain effect on camber can be observed. But a different result accrues when the wing is held firmly by clamps attached to the radius and ulna. It is advisable to clamp the wing horizontally and upside down so that the weight of the quill feathers to some extent imitates the effect on them of the pressure of the air when in use. On fully extending a wing so clamped, the camber is seen to be at its maximum. Flexing at the elbow joint is found to have only a slight effect in describing the camber. On flexing at the carpal ioint the camber decreases

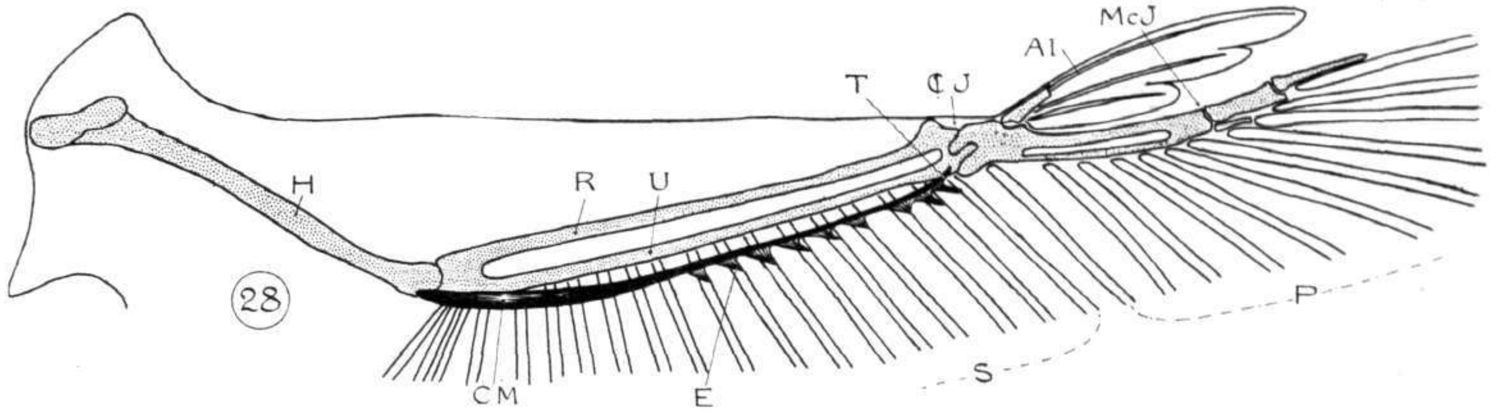
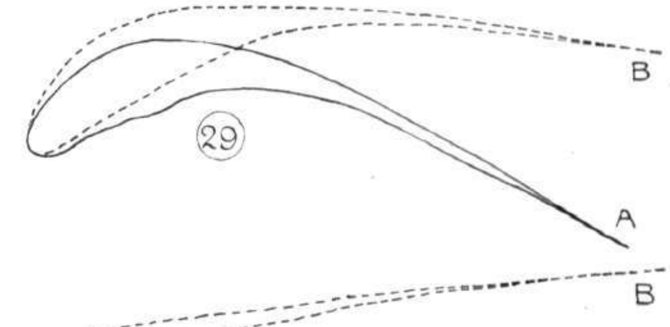
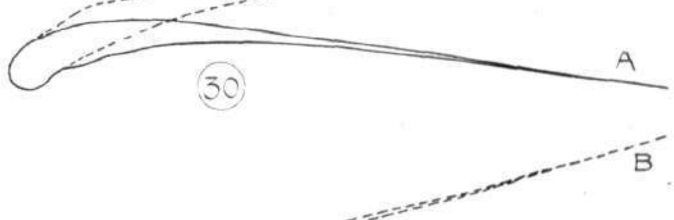


Fig. 28.—Dissection of wing of an adjutant showing "camber muscle." H humerus, R radius, U ulna, C J carpal joint, Al alula, Mc J metacarpal joint, P basis of primary quills (eleven in number in this specimen instead of the more usual number, ten). S bases of secondary quills, C M camber muscle, T insertion of tendon of camber muscle into lower end of ulna. Tendonous extensions (E) of this tendon are inserted into the outer eight or nine secondary quills.





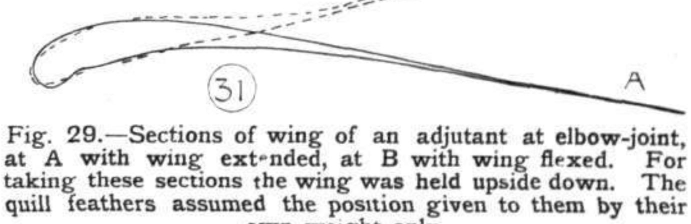


Fig. 29.—Sections of wing of an adjutant at elbow-joint, at A with wing ext·nded, at B with wing flexed. For taking these sections the wing was held upside down. The quill feathers assumed the position given to them by their own weight only.

Fig. 30.—Sections of wing of an adjutant taken at junction of middle and inner thirds of the wing. For taking the sections the wing was held upside down. A weight of 10 grammes was attached to each quill feather to imitate the effect of air pressure, at A with wing extended, at B with wing flexed.

Fig. 31.—Sections of wing of adjutant taken at junction of middle and inner thirds of the wing, at A with wing extended and a weight of 10 grammes attached to each quill feather, at B with wing flexed and a 30-gramme weight attached.

greatly, the decrease being, within limits, in proportion to the amount of flexing. In certain cases in flex-gliding the alula becomes visible in such a way as to prove definitely that the flexing is carpal. That is to say, in flex-gliding the flexing of the wings is an adjustment that, so to speak, automatically diminishes camber. The more the wings are flexed the greater is the decrease of camber, and the greater is the speed. I shall have to describe these changes in greater detail when I bring forward evidence, in a later chapter, as to the direction from which the energy of soarability is operative.

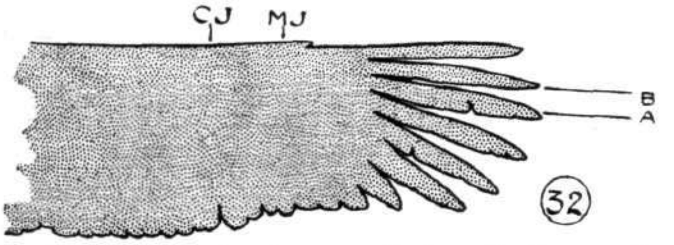


Fig. 32.—Outline of outer part of wing of adjutant when circling with effort to gain height. A, line on prolongation of which is centre of effort of cambered part of the wing; B, line on promulgation of which is centre of lifting effort of phalangeal quills; C J, carpel joint; M J, metacarpal joint.

On the other hand I discovered that if flexing is carried out at the metacarpal joint, no effect on camber is produced. This metacarpal flexing retires the wing-tip, as seen in the descending bird, but leaves the wings at their maximum camber.

There can, I think, be no doubt that the peculiar appearance of the descending bird is due to the flexing being metacarpal and not carpal. I propose the term "metacarpal descent" for the mode of descent now under consideration.

In Fig. 29, I show two sections of the wing of the adjutant bird. In each case A represents the section with the wing fully extended, and B the section taken with the secondaries relaxed by flexing at the carpal-joint. For taking these sections the wing was held upside down. The feathers were consequently merely extended by their own weight.

But in actual flight the feathers must be pressed by a force much greater than their own weight. I attempted to imitate this force by attaching a weight of 10 grammes to each secondary while the wing was held upside down as before. This weight was chosen arbitrarily, but I found that a slight increase or decrease of the weight would have but little effect on the section obtained. The results on the camber are shown in Figs. 30 and 31. It will be seen that with the wing flexed the camber is greatly diminished.

With the aid of the facts now described, it is possible to make a suggestion as to the nature of the adjustment by which the tractive and lifting effort of the cambered wing is put out of action in metacarpal descent.

In Fig. 32 I have drawn the outline of the outer part of the wing of an adjutant as seen when it is circling in not fully soarable air. The line, A, is the line, on a prolongation of which is the centre of effort of the cambered part of the wing. B, represents the line on which is the centre of lifting effort of the phalangeal quills. Thus between A and B there is a couple tending to tilt up the wing or to maintain its angle of incidence.

In Fig. 33 I have represented the outline when the bird is in metacarpal descent. The wing tip is shown retired by flexing at the metacarpal joint. The centre of effort of the cambered part of the wing is on the line A. The centre of effort of the wing tip is on the line B. But as this line, by the retirement, has been displaced backwards, instead of a couple tending to maintain the tilt of the wing, there is a couple tending to decrease its tilt. That is to say the new position of the wing tip results in a tendency to diminish the angle of incidence of the cambered part of the wing.

I think we may regard it as a fact that when the bird changes from ease-gliding or circling to metacarpal descent, it has changed from a mode of flight in which it takes energy from the air to a mode of flight in which it no longer takes energy from the air. The only known change in the disposition of the wings is the retirement of the wing tips. If the wing no longer takes energy from the air it is difficult to imagine that its angle of incidence is the same as before. As may be observed, the angle of incidence is certainly not increased. It is, therefore, probable that retirement of the wing tip either facilitates, or more probably causes, a decrease or abolition of the angle of incidence.

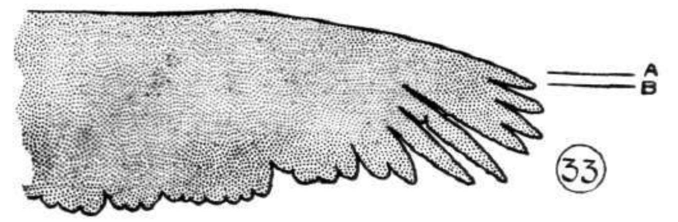


Fig. 33.—Outline of outer part of a wing of an adjutant when in metacarpal descent. A, line on prolongation of which is centre of effort of cambered part of the wing; B, line on prolongation of which is centre of lifting effort of phalangeal quills.

When descending in a strong wind, another mode of descent may be adopted. Flexing of the wings is increased to a greater extent than that usual in fast flex-gliding. The bird accordingly drops through the air feet foremost with the flexed wings extended horizontally. The alula is usually advanced. This mode of descending may be termed "carpal descent." At the end of a metacarpal descent, when speed has sufficiently diminished, there is often a change to carpal descent by further flexure of the wings. I shall describe cases of carpal descent in detail on a later occasion. In carpal, as in metacarpal descent, the angle of incidence appears to be abolished.

The smaller birds frequently descend by a method of a totally different nature, namely, by increasing the angle of incidence without change of course. On a later occasion I shall describe the nature of the adjustment by means of which this change of disposition of the wings is produced.

In carpal descent flexing is chiefly at the carpal and elbow-joints. In diving flexing also occurs at the shoulder-joint, with the result that the greater part of the area of the wings is brought behind the level of the centre of gravity, as shown in the accompanying Fig. 34.

I may close this chapter by considering a point in nomenclature. In speaking of rotation of a wing or of a wing-tip in the preceding chapters, I have implied that the rotation was in such a direction as to lower the anterior margin. As such rotation results in the wing or the wing-tip becoming depressed, it might be described as "rotation downwards." Similarly, in speaking of rotation of the body of the bird round the transverse axis, it will be convenient to describe as "rotation downwards," rotation that depresses the beak and raises the tail. Rotation in the opposite direction, whether of the body round its transverse axis, or of the wings, may be described as "rotation upwards." I shall have occasion to mention cases of rotation upwards when I come to describe my observations on flapping flight.

(To be continued.)

THE MANVILLE PRIZE.

ON Wednesday of last week, the final day of the competition for the Manville prize for the best aggregate flight on an all-British machine with a passenger, attempts were made by Mr. Cody at Aldershot and Mr. Pixton at Brooklands to improve their records. The result was a win for Mr. Pixton, who was already leading, on the Bristol biplane. During the eight specified days on which flying for this prize had been permissible, Pixton had placed an aggregate of 187 mins. to his credit, while Mr. Cody was second with 156 mins. The latter intended to start early on the morning of the 4th inst. to try and improve his position, but a northerly gale put flying out of the question. It was not until ten minutes to five in the afternoon that Mr. Cody was able to get under way, and then he was flying until 5.30, at which hour the competition finally closed. Mr. Cody's record was thus 196 mins. At Brooklands, however, Mr. Pixton was in the air for 129 mins., and so he was an easy winner of the £500 Manville prize with a lead of 120 mins. It will be remembered that Mr. Pixton learnt to fly on the Avro biplane, and it was on this machine that the first portion of his aggregate flights for the Manville and Brooklands competition was carried out. The latter and major part, however, of his flying has been accomplished on a Bristol biplane, on which he has not hesitated to go up when the wind has made the conditions distinctly unpleasant.

A Study of Bird Flight

By Dr. E. H. Hankin. M.A. DSc.

CHAPTER XXIV.—Movements of the Outside Wing Tip in Circling.

I HAVE already described steering movements of the inside wing tip in circling vultures. I have now to describe certain movements of the outside wing tip still more difficult to observe, and whose meaning is obscure.

An example of my first observations relating to this matter is the following:—

March 7th, 1910.—At 1.0.—A large group of vultures circling in Taj Gunj direction. They were from 100 metres up and upwards. Several showed windward dip strongly marked, and also slight arching of outside wind on the windward side of the track.

At first I regarded this movement of the outside wing as identical with the arching that I had already observed in cheels. But I gradually noticed that this arching, unlike that of cheels, only affected the outer part of the wing. Then as I became more familiar with the appearance, I recognised that this false arching was of the nature of a "half-dip movement." But it was only when I arrived in Naini Tal that I was able to make conclusive observations that showed that the false arching in question was of the nature indicated.

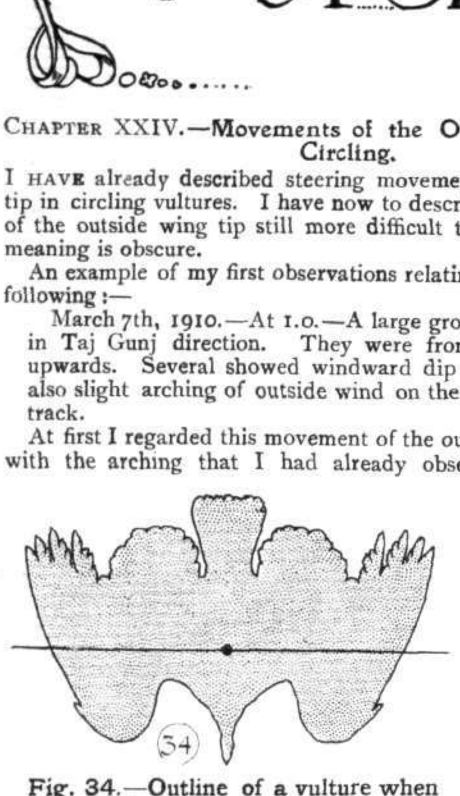


Fig. 34.—Outline of a vulture when diving. Span when wings extended, 85 ins.; span when diving, 40 ins.; weight of bird, 5,520 grammes. The transverse line is drawn through the centre of gravity.

The following are indications of my Naini Tal observations:—

June 19th, 1910.—At Ballia Ravine, 12.30.—A black vulture circling showed windward dip (that is to say, of inside wing) on windward side of track. This was seen to be followed by a slight half dip of outside wind.

June 22nd, 1910.—At Ballia Ravine, 3.45.—A vulture circling with wings nearly flat showed windward dip followed by a half dip of the outer wing. This was again seen shortly afterwards. There were a few small cloud shadows. I formed the impression that vultures circling in sunshine had wings dihedrally up, while the one or two vultures seen circling with wings flat were in shade.

At Ballia Ravine I noticed that, in circling, besides windward and leeward dips, other small dip movements of the inside wing occasionally occurred. In addition, the windward and leeward dips were often followed by slight dip movements of the outside wing tip. These usually last longer than the previously described movements of the inside wing. A half dip of the outside wing may last for several seconds.

These movements of the outside wing tip occur more frequently than otherwise on the windward side of the track, that is to say, at that portion of the circle where there is most canting, and presumably most steering. That is to say, the outside wing tip is occasionally rotated downwards at a time when it should be rotated upwards, if Wright's method played a part in steering movements.

But the movement of the outside wing tip does not seem to be, or always to be, simply a half-dip movement. Occasionally, at least, it is combined with slight retirement of the phalangeal quill feathers. This gives the wing tip a rounded appearance. For instance:—

August 17th, 1910.—At Jharna Nullah. At 11.50.—Sunshine increasing, and circling of larger birds beginning. Adjutants circling with occasional flapping. Light wind.

Some adjutants circling showed clearly rounding of outside wing tip on windward side of track. This was seen three times. Twice also a very slight rounding, merely a slight retirement of the first phalangeal quill was observed.*

* No doubt the succeeding three phalangeal quills were also retired. But it was only in the case of the first quill, thanks to its position, that the movement could with certainty be distinguished.

12.6—Adjutants circling overhead a short way up showed half dip of outside wing along windward side as a depression of first phalangeal quill only. This was often combined with a slight retirement of this feather. This latter movement (extent probably about an inch) was presumably an indication of very slight relaxation of secondaries. It could only be seen when the birds were directly overhead or slightly to windward. As soon as they had drifted past to leeward, the quill feathers seemed to approximate, owing to their being seen foreshortened.

12.50.—Two miles along Tundla Road, beyond Jharna Nullah. An adjutant circling, in nearly complete calm, and well canted over, showed on each of several circles observed, slight alula (perhaps a little more than half an inch) of inside wing on up wind side of circle. While I was watching it the wind increased. The bird then circled with its wings not quite fully extended. No advancement of the alula then occurred. The bird was not so canted as previously. Presumably it was ease-circling. The advancement of the alula, when it occurred, was quite definitely and clearly seen. The bird showed scarcely any leeward drift, so there could not have been much wind at the height at which it was circling.

On one other occasion I have seen advancement of the alula in an adjutant.

The above is the only instance in which I have definitely noted in my diary that the wing tip was retired during the half dip of the outside wing. It must be obvious that both these movements are very difficult to see. The retirement is best seen when the bird is directly overhead. The dip, on the other hand, would be more easily observed when the bird is seen from the side. But the following instance suggests that the two movements are combined:

November 13th, 1910.—At Jharna Nullah.

9.53.—Vultures began circling.

10.14.—Vultures began slow flex-gliding.

10.24.—No half dips or retirement of outside wing tips have been seen as yet, though I had looked carefully for these movements.

10.30.—Besides columns of birds circling and drifting to leeward, vultures were now circling without leeward drift over the slaughter-house. Previously, all circling vultures had shown leeward drift.

10.33.—Vultures seen flex-gliding at medium speed.

10.35.—A vulture seen fast flex-gliding.

10.46.—Many, perhaps a hundred, vultures started to windward of me and drifted overhead at a height of 20 or 30 metres. They were gaining height rapidly. They showed many half dips and retirement of outside wing tips. These occurred both on windward and leeward sides of the circle. They were seen in every vulture that could be observed.

11.32.—Vultures now were circling for the most part with wing tips of both wings slightly retired. This is ease-circling. It had not been observed previously. But vultures at lower levels were circling with wings slightly advanced or straight (tips not retired) and occasionally flapped.

A long time before making these observations, I had noticed in circling vultures that the quill feathers of the outside wing tip were occasionally not as fully extended (that is to say, advanced) as those of the inside wing tip. I was, at first, of opinion that this was a sign that the outside wing did less work in circling, and that, consequently, the bird did not find it necessary to use the muscular exertion necessary for full extension. In view of the facts now described, it appears more probable that this lack of full extension is a sign of slight decrease of camber of the outside wing, which decrease, it may be surmised, is favourable for the relatively greater speed of the outside wing when the bird is travelling on a curved course. When describing my observations in Naini Tal, I mentioned certain cases in which I was able to see a decrease of camber of the outside wing in circling, as evidenced by a slight relaxation of the secondaries. Presumably these cases were of half dips with retirement of the outside wing tip. The fact that while observing the relaxation of the secondaries I made no note of any movement of the wing tips, proves nothing. The relaxation was so very difficult to see that all my attention must have been concentrated on the hind margins of the two wings. Small movements of the wing tip may well have been occurring at the time.

Thus, the exact nature of the movement of the outside wing tip in

circling is still a matter of inference rather than of observation. There is still more doubt as to the significance of the movement. If I am right in supposing that the wing tip retirement is due to carpal and not to metacarpal flexing, then perhaps the movement is some kind of adjustment for steering in a direction opposite to that which would be produced by a full dip movement of the same wing. For instance:—

September 4th, 1910.—At Jharna Nullah, 11.3.—A vulture seen to change from slow flex-gliding to circling by retiring of outside wing tip. No dip of inside wing took place.

The facts hitherto brought forward make it probable that birds possess two distinct methods of steering in the horizontal plane. Facts to be described in Chapter XXXIII will be found to prove definitely that this is the case, and to suggest a simple explanation as to why two methods of steering are required.

CHAPTER XXV.—Observations on a Deformed Vulture.

ANY theory that the use of Wright's method is indispensable for soaring flight must be regarded as disproved by the following observations on a deformed vulture.

The view that lateral stability in birds is produced by a twisting upwards of one wing tip, as the other is twisted downwards, involves a corollary, namely, that in the absence of a balancing movement the wing tip is not so twisted. The deformed vulture, whose movements I am about to describe, has the phalangeal quills of one wing permanently rotated upwards, and apparently immovably fixed.

On the 18th June, 1910, at Naini Tal, I saw a large, brown vulture circling near the top of Sher-ka Danda Mountain. Just before it glided over the crest of this mountain out of sight, it made a circle, which I observed carefully. In so doing it made a dip movement of the right wing. During the time of this dip I noticed that the tip of the left wing was directed upwards to an unusual degree. I thought at the time that I had at last seen Wright's method in use. But on the following day I got a better view of this vulture, and soon saw that the turning up of the left wing tip was due to a deformity. I saw this vulture on several occasions. A few of my observations are comprised in the following extracts:—

June 19th, 1910.—Ballia Ravine, 11.54.—The deformed vulture again started. When turning to the left, half-dip movements of the right wing were observed four times, each half dip being followed by a change of course. After I had made these observations, the bird glided into a cloud and remained out of sight.

June 22nd, 1910.—At Ballia Ravine, 4.55.—The deformed vulture watched through the binocular for about five minutes. It was circling over a hill at about a mile's distance, being only just visible to the naked eye. It always circled with the efficient wing on the inside. Sometimes it turned in the other direction, so that the efficient wing was outside, but this was always only for a short time, and without completing a circle. After circling for several minutes, it ease-glided for about a mile, and went out of sight behind a hill. While ease-gliding, the efficient wing tip was never seen turned up. It seemed to be permanently directed slightly downwards. Dip movements of the efficient wing tip were seen, but at the distance at which it was flying half dips could not be distinguished.

June 29th, 1910.—At Ballia Ravine, 2.55.—The deformed vulture seen circling below my level in the valley below the Brewery (distance of Brewery from me 5,300 feet). While circling, the efficient wing was on the inside, and showed frequent dips of more or less amplitude. The efficient wing tip was always either depressed, or perhaps sometimes horizontal. (*Note.*—If horizontal, there must have been air pressure on the under side of the phalangeal quills). After a few circles had been observed, the bird reversed, so that the bad wing was on the inside. It only made one circle in this direction, during which circle the efficient wing tip remained turned upwards except during two small dips (Figs. 35 and 36). The vulture then reversed to its original direction of circling. A minute later it again made a circle in reverse direction showing the same disposition and movements of the efficient wing tip. Shortly afterwards, during a circle with the efficient wing, as usual, inside, the efficient wing tip was seen to make two dips, one large and one small (the latter presumably a half-dip). The bird then glided out of sight.

3.5.—The deformed vulture again seen. It was observed to turn the efficient wing tip upwards for making a turn.

July 1st, 1910.—Ballia Ravine. At 10.25.—The deformed vulture seen circling with the good wing tip as usual, inside. It raised (rotated up) this wing tip for making a turn, that is to say, for steering in the horizontal plane, preparatory to ease-gliding up the valley.

It must be obvious that the facts described in this and the preceding chapter give ample room for discussion as to the functions of the wing tips. It is to be hoped that the matter may be further elucidated by later observations.

CHAPTER XXVI.—Flapping Flight. The Poising of the Pied Kingfisher.

IT will be found that the study of flapping flight throws an unexpected light on several problems connected with gliding flight.

A difficulty in understanding flapping flight lies in the fact that the bird may, at one and the same time, be making movements

Fig. 35.—Deformed vulture circling with efficient wing tip inside.

Fig. 36.—Deformed vulture circling with efficient wing tip outside.

having different objects; for instance, movements of propulsion, movements in opposition to gravity, movements for balance, and movements for directing its course. In addition, there may be movements or adjustments for checking speed independently of those used before perching.

It is necessary to find a simple form of flight in which the propulsive movement may be studied alone. This desideratum is supplied in a very satisfactory way by the poising of the pied kingfisher in calm air.

The pied kingfisher (*Ceryle Rudis*) differs from other species of kingfisher in having a habit of poising in the air and then suddenly diving down head foremost on to its prey. While poising, the bird appears as if fixed in one position, with its wings in rapid motion. It may remain thus poised for several seconds at a time.

The following measurements were obtained from a specimen of this bird:—

Weight 90 grammes, say	3 ozs.	Area of wings ...	·352 sq. ft.
Span	18 ins.	Loading	·76 lbs.
Length	$11\frac{1}{2}$,,		

In the case of the pied kingfisher poising in still air, since the wings are propelling it vertically upwards, the propelling movement has no admixture with any other movement or disposition for counteracting gravity. Also there are no directive movements, as the bird is not travelling from place to place.

If a pied kingfisher is watched under these conditions, it will be seen that the movement of the wings is not up and down, but to and fro in a perfectly horizontal direction. It will be convenient, however, to use the terms "up stroke" and "down stroke," in describing the movement of its wings.

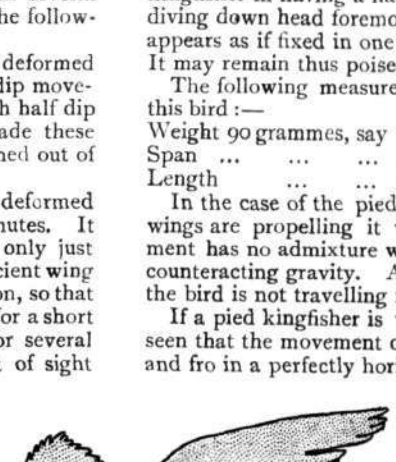


Fig. 37.—Pied kingfisher poising at commencement of down stroke

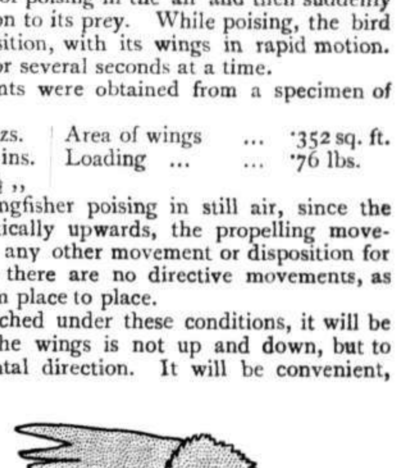


Fig. 38.—Pied kingfisher poising at end of down stroke.

Fig. 37 shows the position of the wing at the commencement of the down stroke. Fig. 38 shows the position at the end of the down stroke.

During the down stroke, as shown in Fig. 39, the wing is moving horizontally forwards. The quill feathers, by the pressure of the air, are bent backwards. The area of the wing, therefore, forms a slanting surface. The pressure of the air on this slanting surface results in a component tending to lift the bird.

The position of the wing during the up stroke is shown in Fig. 40.

Partly owing to the pressure of the air on the feathers, perhaps partly also to the wing having been slightly rotated, the area of the wing now forms an inclined plane, inclined in the opposite direction. As in the former case, there is a resultant force tending to lift the bird.

Because the bird remains in the same place, the lift on the down stroke must equal the lift on the up stroke. If, owing to its shape, the area of the wing is less efficient in lifting on the up stroke, then this lack of efficiency must be compensated by greater speed. Whether or not this is the case in the pied kingfisher it is not possible to see, owing to the extreme rapidity of the beats when poising. But in the case of some larger birds, and in the case of the flying fox, I have been able definitely to observe that the movement of the wings when in horizontal flight is faster on the up stroke.

In the poising pied kingfisher the strokes are of much greater amplitude than they are in ordinary horizontal flapping flight. At the end of the down stroke the wings nearly meet in front of the body. At the end of the up stroke the wings nearly meet behind the back. Fig. 41 shows the bird as seen from in front when the wings are coming together near the end of the down stroke. It must be obvious that the two wings, when approaching, tend to squeeze out air from between them in a downward direction, thereby, in a small degree, aiding the lifting effect. Fig. 42 shows the bird, again as seen from in front, when the wings are receding from one another at the commencement of the up stroke. Owing to their movement there must be a tendency for the air to be sucked in from above. That is to say, there is again a slight addition to the lifting effect.

It must be obvious from this description that the poising kingfisher resembles a horizontally-placed propeller whose blades reverse every half-revolution.

Fig. 43 represents a pied kingfisher poising, not in calm air, but in a wind. Under these conditions the direction of the strokes of the wing is no longer horizontal, but slightly inclined to the horizon. The arrow W represents the wind direction. The arrow R represents the direction of the propelling effect of the wings. As in the first case, it must be obvious that propelling work is being done on the up stroke besides on the down stroke.

I was once watching a pied kingfisher poising in a calm. It was struck by a puff of wind, as shown by ripples that appeared on the water below it. The consequent change in the direction of the beats of the wings could be clearly seen. Owing, no doubt, to this change, the bird was not blown to leeward, but retained its position.

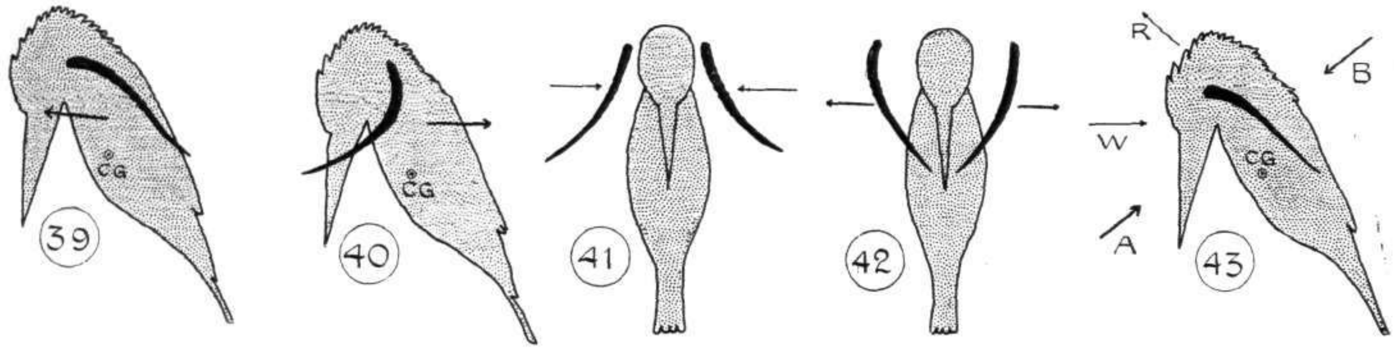


Fig. 39.—Position of wing of poising kingfisher during down stroke. Fig. 40.—Position of wing of poising kingfisher during up stroke. Fig. 41.—Front view of poising kingfisher near end of down stroke. Fig. 42.—Front view of poising kingfisher at beginning of up stroke. Fig. 43.—Side view of kingfisher poising in a wind. The arrows, A B, show direction of beat of wings, C G centre of gravity, W direction of wind, R direction of propelling force of wings.

When the pied kingfisher is flying from place to place its mode of flight is quite different from that seen in poising. The long axis of the body is horizontal (or nearly so), instead of being strongly inclined as in poising. The direction of the beat of the wings appears to be vertically up and down. The rate and also the amplitude of the beat is lessened.

So far as we have gone in considering flapping flight, everything appears to be explained with one important exception, namely, what is the adjustment by means of which the kingfisher can change from poising to cross-country flight? Obviously, to do so, the bird has to rotate round its transverse axis. The method of rotating round this axis that is used in gliding flight is clearly not applicable. The discovery of the method used in flapping flight will be described in the next chapter.

(To be continued).

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AIRSHIP NEWS.

The Naval Airship Disaster.

THE fact that Mr. McKenna, First Lord of the Admiralty, and Lord Haldane, Minister of War, were present at the opening of the inquiry on board H.M.S. "Hermione," on Wednesday of last week, into the disaster to the Naval dirigible points to the importance which is attached to the event at headquarters. The Commission consists of Rear-Admiral Sturdee, chairman, Capt. Nicholson, and Mr. Whiting. Before the proceedings opened, a visit was made to the wreck of the airship. Some 200 Marines were examined by the Commission as to their knowledge of the accident, and among others present at the inquiry were several aeronautical experts from the Admiralty and three of the Army airship officers.

The "Schwaben's" Record.

DURING the 54 days she has been in service the Zeppelin liner "Schwaben" has made 81 ascents, and this includes nine long voyages ranging from 200 to 400 kilom. She has been in the air for 187 hours altogether, has covered 10,811 kilom., and carried 1,675 persons. It is proposed in a few days to make an excursion from Dusseldorf into Holland, and then in November the vessel will return to Frankfort, where she will be permanently stationed.

"Schwaben" goes to Dusseldorf.

ON the 13th the Zeppelin liner "Schwaben" left Baden Baden with five passengers on board, and passing by Heidelberg and Darnstadt reached Frankfort after a trip of 3 hours. A stop was made there for just an hour and then *via* Mayence, Coblence and Bonn, the dirigible went on to Dusseldorf, which was reached after 3½ hours. During this time the misty conditions made steering a difficult task, and several times the vessel got off her course. The full distance covered was about 300 kiloms.

"Parseval VI" Returns to Bitterfeld.

AT half-past ten on the morning of the 13th, "Parseval VI" was brought out from her shed at Johannisthal and sailed over to Bitterfeld, the journey taking about three hours.

The "Schutte-Lanz" Makes its Début.

AT last the "Schutte-Lanz" dirigible, which it will be remembered is of the rigid type with a wooden framework, has made its appearance in the open, it having made a short cruise on Tuesday last. The wooden framework is 430 ft. and 60 ft. diameter at its biggest section. Extensive experiments in wireless telegraphy are to be carried out with this airship.

A Long Voyage by "Adjudant Vincenot."

ON the 6th inst., the Clement Bayard dirigible "Adjudant Vincenot" was brought out of its shed at Lamotte Breuil and was sailing for just on three hours over Soissons, Courcy-le-Chateau and Compiegne. She carried a crew of eight persons.

The New Transatlantic Dirigible.

SOME particulars are to hand of the new dirigible "Akron" with which Mr. Melvin Vaniman proposes to attempt a transatlantic trip this month. The envelope has been made by the Goodyear Tyre Co., of Akron, and is 268 ft. long and 45 ft. diameter at the largest section. It is made up of 2,200 pieces of fabric 1·03 in. thick, consisting of three layers of cotton cloth interleaved between four layers of rubber.

A Study of Bird Flight

By Dr. E. H. Hankin, M.A. DSc.
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Chapter XXVII.—Movements Round the Transverse Axis in Flapping Flight.

It is a matter of common observation that just before perching a bird usually makes a few flaps of its wings. These flaps may seem a trivial matter to investigate, but it will be at once apparent that they are of considerable theoretical interest.

My first observation concerning this matter was as follows :—

June 26th, 1910.—At Ballia Ravine, 1.34.—A vulture seen gliding up the valley to settle. When near the tree on which it was about to perch, it flapped in order to gain height or speed. The direction of the flaps could be clearly seen to be up and down. Then for a few metres it glided without flapping. Just before perching it hung down its body and again flapped. The direction of these flaps was quite clearly seen to be fore and aft. That is to say, these flaps were meant to act as a brake.

For the sake of clearness, I show these different stages in the process of settling in Fig. 44. At A the bird is shown gliding. Then at B it is shown flapping with strokes apparently vertically up and down, as shown by the direction of the arrows. At C the bird is again gliding, and its feet are hanging down. At D and E the bird continues to glide, but the legs and also the body are hanging down. At F the bird is again flapping, but with the beat of the wings in a fore and aft direction. That is to say, before this flapping commenced, or as it commenced, the wings rotated through a right-angle. To this form of flapping I propose to give the name of "stop flapping." In a later paragraph I shall explain the difference between stop-flapping and the flapping used by the poising kingfisher. The latter form of flapping lifts the bird. Stop-flapping, on the other hand, has no appreciable lifting effect, but tends to check the forward motion of the bird through the air.

Shortly after making the above observation, I noticed a cheel settling. In this case there was no hanging down of the body before the commencement of stop-flapping. At the moment that the stop flapping commenced, not only did the wings change their plane of action, but also there was a simultaneous rotation upwards of the whole bird round its transverse axis. How this rotation occurred was shown to me by observation of yet another cheel that did not perch by the usual method, but by the procedure shown in Fig. 45. At A this cheel is shown gliding towards its perch with the wings "straight," that is to say, with their centre of effort nearly or quite on a level with their centre of gravity. The first preparation for perching made by this cheel was to put its wings in the "advanced" position as shown at B. The bird immediately began to rotate round its transverse axis, as shown at C. After the rotation had occurred, stop-flapping began, as shown at D. That is to say, stop-flapping occurred with the wings in the advanced position.

The explanation of this rotation round the transverse axis is both obvious and simple. In Fig. 46, at A, a bird is shown with its wings in the dihedrally up position. This, as already explained, produces a couple tending to rotate the bird upwards round its transverse axis. Obviously, this result depends on the resistance that the wings or wing tips experience to forward motion through the air. Therefore it is an adjustment that must be more efficient the faster the bird is moving. If the bird is gliding slowly, or if the bird wishes to check its speed, a different adjustment is employed. The wings are placed in the advanced position, as shown in Fig. 46 at B. When in this position the wings present a resistance to dropping downwards through the air that may be regarded as concentrated at a point, which point must be in advance of the centre of gravity. Hence there must be a couple that rotates the bird round its transverse axis. This, in fact, is the method used by cheels, crows, scavenger vultures, parrots, and other birds in settling either with or without stop flapping. It is noteworthy that advancing the wings causes rotation round the transverse axis, but no direct change of course. A scavenger, gliding downwards at a small angle with the horizon, may be seen suddenly to slightly advance its wings. The result is a slight rotation of the whole bird, including the wings round the transverse axis. That is to say, the angle of incidence is increased. Hence the wings act as a brake, and speed decreases. As the bird gets nearer its perch there may be a further advancing of the wings. The consequent further rotation round the transverse axis acts as a stronger brake, so that the bird may drop vertically on to its perch. In a slight wind, an eagle, for instance, may stop without any stop flapping. It is striking to see the bird gliding along at a height of two or three feet from the ground, suddenly drop its legs, and perch on a shrub or other projection without any apparent effort to check its speed beyond the advancing of the wings and expansion of the tail. While thus checking speed the tail is expanded and depressed, so that its surfaces may, in some cases, be placed almost at a right angle to the line of flight. In the case of the green parrot, stop flapping always occurs, and the wings may clearly be seen to be in an advanced position.

Rotation round the transverse axis may also occur when the bird is swooping downwards at high speed. If in such a case the rotation is caused by advancing the wings, there is no change of course, but speed is checked. If, on the other hand, in the case of cheels, rotation is caused by placing the wings in the dihedrally-up position there is a change of course and less loss of speed. This

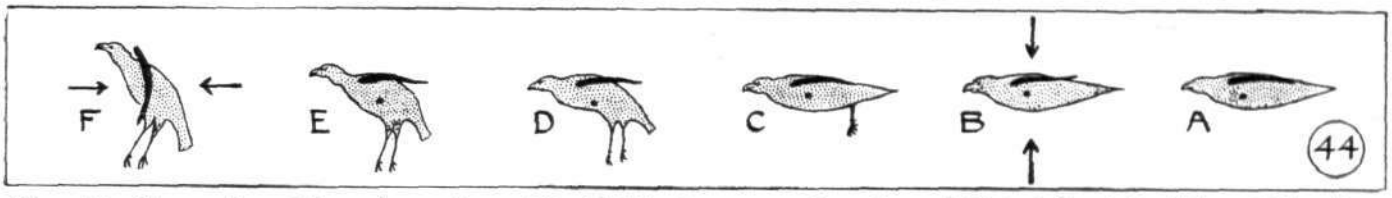
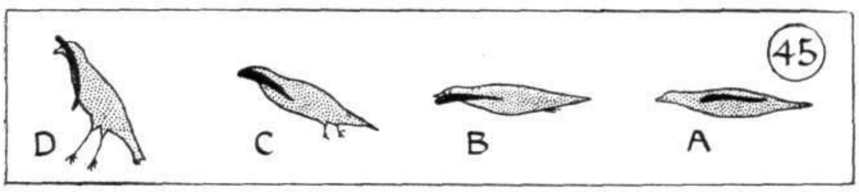


Fig. 44.—Stages in settling of a vulture. The bird is shown travelling from right to left—at A gliding, B flapping for a short distance. The arrows show the direction of the strokes. C again gliding, but with feet hanging down; D and E, body beginning to hang down below level of wings; F, after rotating through nearly a right angle, the wings have commenced "stop flapping." As shown by the arrows, the direction of beats in stop flapping is nearly horizontally to and fro.



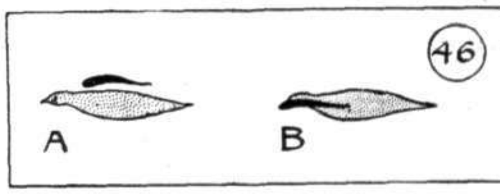


Fig. 45.—Stages in settling of a cheel—at A gliding; at B the wings are advanced, in consequence the bird rotates round its transverse axis as shown at C. At D stop flapping has commenced.

Fig. 46.—Diagram showing two methods of rotating round transverse axis. At A the wings are placed dihedrally upwards; at B the wings are shown advanced. Either disposition results in a couple tending to rotate the bird upwards (beak up, tail down) round the transverse axis.

is the adjustment used by cheels when swooping downwards to snatch a piece of food from the ground, or occasionally from a tray carried on a man's head. The food is always seized by the feet. The bird swoops down, catches the food without interruption of its flight, and glides upwards almost to its original height. This curved course is due to delicately applied adjustment of the dihedral angle. On the other hand, as already described, in diving, placing the wings suddenly and strongly in the dihedrally-up position, causes a sudden rotation, and consequently acts as a break. Another case n which the dihedrally-up position acts as a break will be described in the chapter on the functions of the tail.

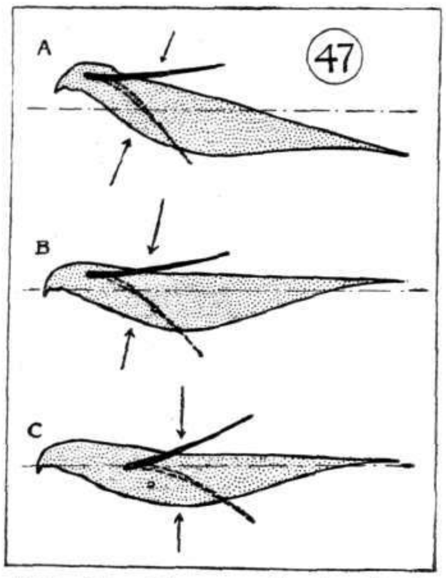


Fig. 47.—Diagram showing horizontal flapping flight at different speeds. A, slow; B, medium; C, fast. The arrows show the direction of beat of the wings. Note that the slower the flight the more are the wings advanced. The cause of this will be explained in a later chapter. In each figure the wing section drawn as a continuous line represents the disposition during the down stroke. The dotted line represents the disposition during the up stroke. B may be taken to represent the ordinary flapping flight of the larger birds. C is only seen in fast flight of small birds.

Conversely flapping with the wings retired must cause rotation round the transverse axis in the opposite direction. This, in fact, corresponds with my observations. Both in the case of pigeons and green parrots, when flying downwards, I have been able to see that their wings are flapped in the retired position.

In slow horizontal flight the wings are flapped in a more advanced position than in fast horizontal flight. Hence, in slow horizontal flight (Fig. 47 A), during the down stroke, the wings move downwards and forwards. In fast, horizontal flight, this forward trend of the wings on the down stroke, if it exists, is too small to be observed. (Fig. 47 C.)

In the case of the adjutant, I have been able to observe the change from flapping with wings advanced to flapping with wings straight. The following is an extract from my diary :—

August 8th, 1910.—At Jharna Nullah. 6 p.m.—About 200 adjutants were settled. No birds up, not even cheels, except a few birds in flapping flight, mostly when disturbed. The air was nearly calm, after a succession of showers. Sound travelled far. The noise made by the beats of the wings of adjutants and vultures, if they started flying, could be clearly heard, even when the birds were at some distance from me. I sent a boy to start the adjutants. This he did cleverly in such a way that they got up, generally one at a time, and flapped past me broadside on. I thus observed the movements of between 50 and 100 of these birds under very favourable conditions. The advance of the wings on the down stroke was clearly seen in adjutants in horizontal flight. In the case of an adjutant that was flying upwards at an angle with the horizon, the advancing was still more marked, so that the direction of the beats was nearly horizontal.

After they had flapped to a height of between 10 and 15 feet, several adjutants were seen to commence gliding. The last two flaps before gliding were, in each case, directly up and down without any advancing on the down stroke. Presumably in flapping with advanced strokes, the centre of effort of the wings was in advance of the centre of gravity. The two straight up and down strokes were carried out with the centre of effort, vertically above the centre of gravity. That is to say, these two flaps were a preparation for gliding in a horizontal direction. They indicated an approximation of the centre of effort and centre of gravity, as must occur when gliding in unsoarable air.

The following observations are of importance :—

September 25th, 1910.—At Jharna Nullah, at 10.30 a.m.—An adjutant flapping with wings advanced was seen to change to straight up and down flapping as a preparation for gliding. At the moment of this change, rotation downwards of the body of the bird round the transverse axis was clearly seen. This rotation may have been about 5°.

An adjutant gliding downwards at a small angle with the horizon was seen to change its direction, and glide slightly upwards for several metres before commencing flapping flight with wings in advanced position. The difference between the two directions may have been as much as 10°.

That is to say, in these cases the transverse axis rotation caused by changing the wings from the advanced to the straight position was actually observed.

Cheels when gliding are often followed and teased by crows. Under these conditions, to escape the crows, they sometimes make a sudden flap, which changes their direction, causing them to rotate on the transverse axis, and glide upwards. At other times they make a flap which changes their course to a downward direction. At the time of first seeing this, I was unable to understand how a beat downwards of the wing could cause the bird to travel downwards. Now, it must be clear, in this latter case the wing was flapped when in the retired position.

The following observation also receives an easy explanation :—

July 5th, 1910, at 5.9.—A stormy soarable wind. A cheel seen gliding up wind about 3 metres above the roof of my house where I was sitting. Three crows were in attendance teasing the cheel. The cheel was gliding with wings flexed, and the wings were seen to be frequently advanced or retired. Each movement, whether forward or backward, shifted the wing tip about half an inch from its normal position.

In the light of our present knowledge, it appears probable that the advancing and retiring of the wings were movements preparatory for flapping in either an upward or a downward direction. This is a first example of an "anticipatory movement." Other cases of anticipatory movements will be described in the sequel, one of which will be seen to be of some theoretical importance.

Postscript.—Since writing the preceding chapter, I have found that Lilienthal discovered that rotation round transverse axis may be produced by advancing the wings. He expressed himself on this subject as follows :—

"Accordingly the bird can easily do without its tail, as it possesses another highly efficient means of rising or sinking in the longitudinal direction. In order to be raised longitudinally it is only necessary for it to shift forward its wings, and so to advance their centre of supporting effort. Similarly by drawing its wings backwards, the front part of the bird sinks. This latter movement is used by birds of prey when diving from a height."—("Der Vogelflug," page 73.)

(*To be continued*).

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Mr. Hucks Concludes His Tour.

LAST week Mr. B. C. Hucks concluded his three months' tour in the West of England, at Gloucester, where he made flights each day. During the early part of the week the wind was very troublesome, but on Monday he was out twice, and on Tuesday three times. Wednesday was much more suitable for flying, and Mr. Hucks started off with a trial of 18 mins., during which he got up to a greater height—800 ft.—than the Cathedral. In a second trip he got up to 1,000 ft., while in a third he made an attempt to beat his own altitude record of 3,500 ft., but was not quite successful. On Thursday four flights were made, and in the second Mr. Hucks came down in the local football field, causing a stampede among the players. The concluding flight was in the nature of bomb-dropping practice, when Mr. Hucks made some very good shots. With the wind blowing at a rate of 30 to 35 miles an hour, work on Friday was limited to two flights, one of 6 minutes, and the other of 35 minutes, Cheltenham, where an exhibition had been given during the previous week, being visited during the latter excursion. The worst weather of all was experienced on Saturday, when the wind got under the hangar and lifted it and the machine clear of the ground. Fortunately the damage done was not very great, and the mechanics were able to get the machine in trim again by a quarter to five in the afternoon, when Mr. Hucks made three short flights in a very gusty wind.

A Model Club for Worcester.

MR. STANLEY A. SEARS, head of the engineering department of the City of Worcester Victoria Institute Science and Technical Schools (Sansome Walk, Worcester), has been approached by some of his students with respect to the formation of a model aeroplane club in the Worcester district.

Mr. Sears would be glad to hear from anyone interested in this matter, with a view to calling a preliminary meeting.

A Study of Bird Flight

By Dr. E. H. Hankin, M.A. DSc.

Chapter XXVIII.—The Position of the Wing Tips in Flapping Flight.

The facts to be described in the present and in the succeeding chapter will be found to give an answer to the important question as to what is the cause of the difference between lift-flapping and stop-flapping. In each case the direction of the strokes is horizontally to and fro. In the case of lift-flapping of the poising kingfisher, work is done both on the up stroke and on the down stroke. In the case of stop flapping, there is no demonstrable lifting effect, and work appears to be done on the down stroke only, and is in such a direction as to tend to check the forward progress of the bird.

If there is a resemblance between the action of the wings of the poising kingfisher, and the action of the wings when in horizontal flight, then certain consequences must follow. Firstly during the down strokes in horizontal flight there must be some yielding of the hinder part of the wing area. That is to say, when the wing is being moved downwards, its surface cannot be perpendicular to the air against which it presses. It must have such a position that the wing, when descending, forms an inclined plane, and hence drives the air backwards besides downwards. The presumed disposition of the wing on the down stroke is shown in Fig. 48. Secondly, during the up stroke, as shown in Fig. 49, the wing must bend in the opposite direction. As a matter of fact the secondary quills are attached to the wing bones in such a way that they easily yield to the air pressure during the up stroke, under all circumstances. I have once or twice observed a vulture flapping towards the west in the afternoon, and noticed that during the up stroke the sun illuminated the underside of the wings. During the down stroke the underside of the wings remained in shadow, thus proving that there is a difference in the inclination of the wings during the up and down strokes of the nature above suggested.

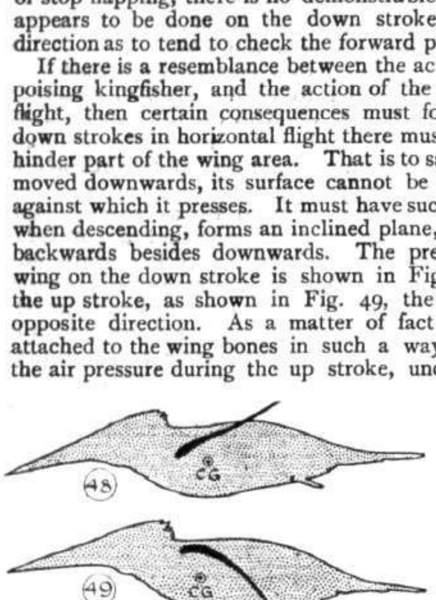

Fig. 48.—Pied kingfisher in fast horizontal flight, showing position of a section of a wing during the down stroke. C G centre of gravity.
Fig. 49.—Pied kingfisher in fast horizontal flight, showing the position of a section of the wing during the up stroke.

But it has already been shown that the secondary quill feathers are so attached that they do not yield on the down stroke if the wing is fully extended.

Therefore, if horizontal flight resembles poising in the manner suggested, then ordinary horizontal flapping-flight must take place with the wings not quite fully extended. The following extracts from my diary show that some practice was necessary before I was able definitely to determine that this is the case. The first quotation is a continuation of my observations made on August 8th.

I looked carefully to see whether the wing (of adjutants) was fully extended during flapping flight. I was able to see that at the top of the stroke the primary quills were not so fully extended as they are in circling. Probably the first primary quill could have been advanced about two inches more than was the case. I saw also, but with less certainty, this lack of full extension at the bottom of the stroke. It was to the same amount as at the top.

August 12th, 1910.—At Jharna Nullah. 5.15.—Three adjutants flapping showed all through both up and down strokes the wing-tips less than fully extended. Adjutants flap-gliding, with gliding intervals of only one or two seconds, did not make vertical up-and-down strokes before the glide. Wind west, moving leaves. Heavy clouds. No birds up except in flapping or flap-gliding flight.

August 14th, 1910.—At Futteypur-Sikri. 8.45.—A black vulture passed near flap-gliding. When flapping, its wings were less than fully extended by about three inches. During the periods of gliding its wings were fully extended.

August 27th, 1910. At Jharna Nullah. 11.50.—An adjutant seen making "half-flaps" (*i.e.*, flaps of less than usual amplitude) while circling. It was noticed that during the half-flaps the wings were not fully extended. While gliding round the rest of the circle, the wings were fully extended.

12.0.—Adjutants flap-gliding at low-level. When flapping their wings were not fully extended. At the moment that flapping ceased to commence a period of gliding, a sudden extension of the wing tip was observed. In the case of adjutants flap-gliding at a higher level, this extension could not be seen, as they glided (presumably in more soarable air) at higher speed with wings slightly flexed.

12.6.—A vulture flapping. A sudden extension of the wing tips seen as it commenced to circle.

Since making the above observations, it has become quite easy for me to see the retirement of the wing tip in flapping flight of cheels, vultures, and other birds.

The above is an example of a case in which by practice I learnt to make an observation with ease that at first could only be made with difficulty. In such cases it has more than once happened that with increased power of observation, I have arrived at quite unexpected results. This is exemplified in the present case by the following observations:—

September 24th, 1910.—At Jharna Nullah. 11.45.—Several vultures and three adjutants circling. They flapped occasionally when at low level. Weather fine. From 1.0 p.m. onwards there were small isolated cumulus clouds.

A vulture flapping directly overhead, a few metres up, showed its wings during the up stroke less flexed than during the down stroke. A minute later this was more clearly seen in the case of another vulture, whose wings were more flexed than usual during the down stroke. Shortly afterwards I saw the same phenomenon in an adjutant; but in this case the flexing seemed to gradually decrease during the up stroke, and was followed by sudden flexing at the commencement of the down stroke.

October 6th, 1910.—At Sekundra Road Refuse Pits. 11.5.—Adjutants starting. At first flap-circling. Then in a minute or or two circling. After a few minutes slow flex-gliding.

11.20.—Adjutants fast flex-gliding. The wing-tips were retired perhaps as much as 45° with the front line of the rest of the wings. The speed was 7 metres per second against a rather strong wind. This was at a height of 300 metres.

11.26.—An adjutant noticed circling with wings slightly advanced. (Presumably circling had hitherto taken place with wings straight. The advancing is a sign of increased soarability of the air.)

11.27.—An adjutant, starting, flapped past me at a height of about 5 metres over my head. It showed clearly the wing tip extending during the up stroke, and the sudden flexing at the beginning of the down stroke.

This advancing of the wing tip during the up stroke appears to be a matter of interest. As to its cause, there are two possibilities. Firstly, it may be due to direct muscular action of the intrinsic wing muscles. If this were the case, then the extra extension must be advantageous; that is to say, the extension must aid the wing doing work during the up stroke. Secondly, it is possible and more probable that the extending is not due to muscular action, but to the effect of air pressure on the upper surface of the secondary quills. As a matter of fact, in the dead bird pressure on the upper surface of the secondary quills causes extension of the wing tip. There is also the possibility that the extension during the up stroke is due to centrifugal force. But, at all events, this extension can only occur if there is a change in the position of the secondaries, such as may be caused by pressure of the air.

I have long been acquainted with the fact that the wing of the crow does not appear to move vertically up and down during fast horizontal flight. The tip of the wing (as compared with the base of the wing) appears to move in an ellipse whose long axis is nearly vertical. This appearance cannot, in my opinion, be explained by the above observations on adjutants. In the case of the adjutant, the extension can only be seen when the bird is flapping overhead at quite a short distance. Even then the observation can only be made after practice. It is extremely improbable that extension on the up stroke, should it occur, could be seen in so small a bird as the crow. The appearance must have some other cause.

The facts described in this chapter appear to leave little room for doubt that in horizontal flapping flight a propelling effect results from both the up and the down strokes of the wing.

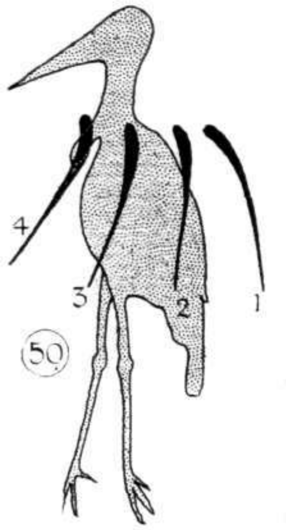

Fig. 50. — Rotation of wing of adjutant in stop flapping. The section of the wing is taken at the junction of middle and inner thirds of the wing. The numbers 1 to 4 show successive positions during the down stroke. During the up stroke the same positions are assumed, but in the reverse order. Note the pouch hanging from the neck of the bird. In some cases this pouch is more than a foot long.

CHAPTER XXIX.—Stop Flapping.

In stop flapping it is advantageous that the wings during the down stroke should get as much grip on the air as possible. Hence, as can be very easily seen, in stop flapping the down stroke is made with the wings fully extended and consequently with maximum camber. An illustration of stop flapping showing the full extension besides advancing of the wings, in the case of the green parrot, has already been given in Fig. 20.

During the up stroke in stop flapping the wings also remain fully extended. As already explained, this full extension does not prevent the seondary quills yielding to the pressure of the air. Hence, if the preceding was the only evidence available, we should have to conclude that lifting work was done during the up stroke. But the following observations show that certainly in some cases, possibly in all cases, no lifting work of this nature is done.

September 20th, 1910.—At Jharna Nullah. 5.15.—Slight clouds. All birds settled except cheels and eagles skimming over the buildings. Some adjutants on being disturbed flapped across a shallow ravine. One turned slightly while over this ravine to settle on a wall. That is to say, it had to lose speed more quickly than would have been the case had it been alighting on level ground. During the stop flapping its wings could be clearly seen to rotate with each stroke. The rotation was such that on the down stroke the posterior margin of the wing must have been flapped forward about two or three inches more than would have been the case had there been flapping only without rotation. A few minutes later another adjutant was seen to rotate its wings while stop flapping in the same way. (Fig. 50.)

On a later occasion (November 12th) I succeeded in seeing similar rotation during stop flapping in the case of a vulture. This bird was settling on the top of a wall.

It is obvious that the check to forward movement produced by the down stroke must be increased by this rotation of the wings. The rotation in the opposite direction during the up stroke must also tend to prevent this stroke having any lifting action. It is probable that this movement is one only visible in extreme cases, as, for instance, when the bird has to stop suddenly in nearly calm air for perching on a wall, &c. It is also probable that rotation occurs in other cases but to an amount too little to be directly observed.

In the case of the adjutant when settling, lift flapping may occasionally be observed besides stop flapping, and the difference between the two kinds of movement can be clearly appreciated. For instance :—

August 18th, 1910. At Jharna Nullah. 5.35. Several adjutants seen settling. Just before reaching the ground they made one or two flaps with wings fully extended. Then, when their feet had reached the ground they made two or three flaps with the wing-tips less than fully extended by three or four inches. Both kinds of flaps were in a nearly horizontal direction. Those with the wings extended were ordinary stop flapping. The other flaps apparently were lift flapping to ease the strain as the weight of the bird came on to its legs.

In the case of flying foxes, I have occasionally seen an apparent sudden rotation of the wings through nearly a right angle used as a break to check speed suddenly when in horizontal flapping flight. This usually occurs to avoid a collision. In horizontal flight the wings may be seen to be flapping up and down (or perhaps generally slightly advanced with appearance of advancing on the down-stroke). In the cases mentioned the wings seem to suddenly rotate through nearly a right angle and to be flapping to and fro. But in two cases I have been able to see that this to and fro flapping occurred with the wings advanced. Probably this advancing of the wings always occurs under these conditions. Flying foxes may frequently be seen to advance their wings for poising before perching. This poising, as in the case of the kingfisher, occurs with the wings advanced and in to and fro horizontal flaps. The poising only lasts as a rule for a second or two. The hind feet then may be seen to move forward and to clutch the bough. The bat then falls over in any direction and remains hanging by its feet.

CHAPTER XXX.—Half flaps. Rate of Beat in Flapping.

The facts described in the preceding chapters indicate that the wings propel during the up stroke besides during the down stroke, whether the bird is poising in calm air or whether it is moving forward horizontally. In the latter case the wing must give gliding support during the down stroke. This can only occur sufficiently when the position of the wings is not far from the horizontal. Hence in horizontal flight the amplitude of the beats is diminished. Also the slower the flight the less in the range of the beats. Some examples of the range of beat under different conditions are given in Fig. 51.

A proof that horizontal flapping flight consists of propelling movements with gliding superadded is furnished by the existence of what I propose to term "half flaps," that is to say flaps in which the range of beat is unusually limited. Crows in Naini Tal when circling occasionally show half flaps. I have seen vultures make half flaps after flap-gliding, and before commencing to flex-glide at a time when the morning development of soarability was taking place. A parrot when settling may make half flaps with the wings dihedrally up and advanced. In this case the range of beat of the half flaps may be between an inch and half an inch. Half flaps when settling with the wings somewhat similarly disposed may be shown by flying foxes. Occasionally kingfishers and adjutant birds may make half flaps when settling. My notes contain mention of half flaps made by a butterfly (*Papilio ravana*) that I often observed in Naini Tal gliding for considerable distances without movement of the wings. Half flaps vary in their amplitude. That is to say there is every intermediate form of movement between gliding and flapping flight.

In poising, maintenance of the bird in the air is due to the beat of the wings alone. In horizontal flight there is also the effect of gliding to prevent loss of height. Hence one would expect that in poising the rate of beat should be quicker than in horizontal flight. In the case of the pied kingfisher, when poising, the rate of beat is

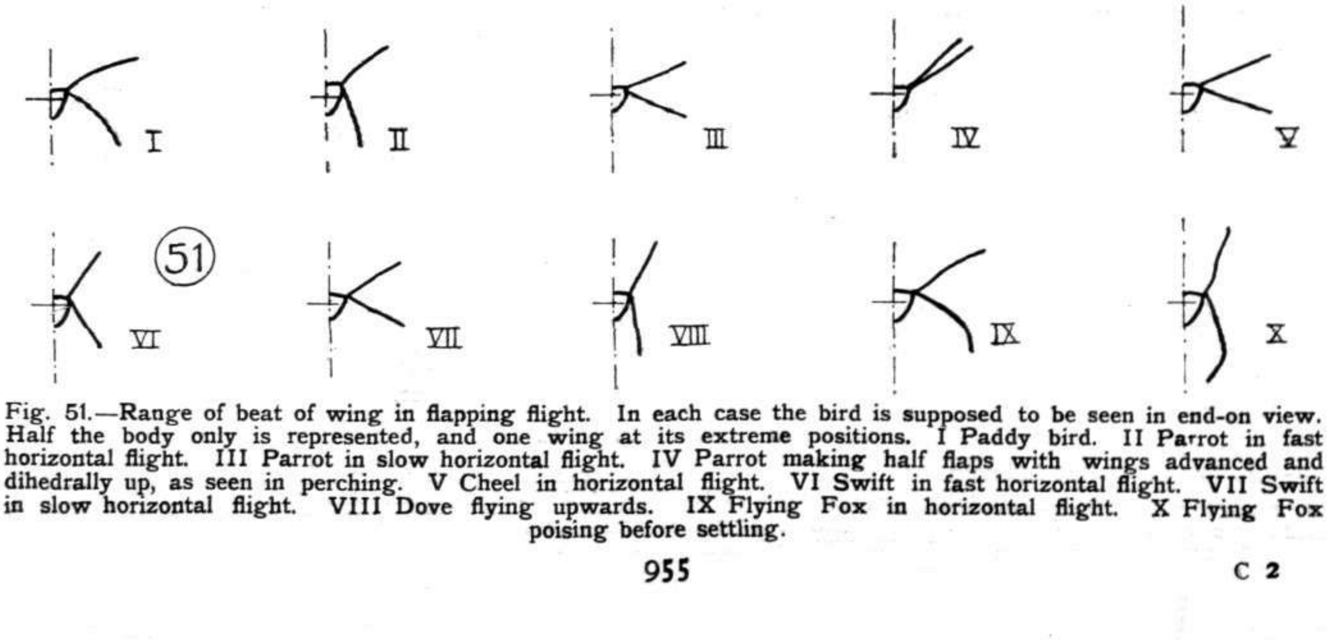

Fig. 51.—Range of beat of wing in flapping flight. In each case the bird is supposed to be seen in end-on view. Half the body only is represented, and one wing at its extreme positions. I Paddy bird. II Parrot in fast horizontal flight. III Parrot in slow horizontal flight. IV Parrot making half flaps with wings advanced and dihedrally up, as seen in perching. V Cheel in horizontal flight. VI Swift in fast horizontal flight. VII Swift in slow horizontal flight. VIII Dove flying upwards. IX Flying Fox in horizontal flight. X Flying Fox poising before settling.

too rapid to count. In some cases it is possible to see that the wings are moving to and fro with great rapidity. In one case, in twilight, the wings appeared to me as a great halo surrounding the bird. In horizontal flight the rate of beat is certainly less. The rate of beat of the flying fox in horizontal flight is usually from ·3 to ·4 of a second. Occasionally for short distances it may be slower. When poising, as may occur before perching, the rate of beat is greatly increased and too rapid to count. As with the kingfisher, the amplitude of the beats in poising is also greater than in horizontal flight. The flying fox, in horizontal flight, usually arches the wing at the bottom of the down stroke (Fig. 51, IX). On one occasion I was able to see that in poising the arching at the bottom of the stroke was greatly increased, so that the wings nearly met in front of the body at the end of the down stroke (Fig. 51, IX).

By the term "beat" I intend to imply an up stroke plus a down stroke. The following table gives the rate of beat, during horizontal flight, of different species of birds that have come under my observation :—

Swift (*Cypselus affinis*)	·1 sec.
Green parrot (*Palaeornis torquatus*)	·15 to ·25 sec.
Blue jay (*Coracias indica*)	·3 sec.
Crow (*Corvus splendens*)	·3 to ·4 sec.
Paddy bird (*Ardeola grayi*)	·4 sec.
Black vulture (*Otogyps calvus*)	·4 ,,
White scavenger vulture (*Neophrons gingianus*)...	·45 ,,
Adjutant (*Leptoptilus dubius*)	·5 to ·45 sec.
Cheel (*Milvus govinda*)	·4 to ·45 ,,
Two or three species of wading birds	·5 sec.

Some facts in my possession lead me to suspect that the rate of beat in the case of birds flying long distances varies with unknown atmospheric conditions. The matter would probably repay investigation. (*To be continued.*)

THE GOVERNMENT AND AEROPLANES.

AT last there is a serious move to be made by the British Government in really helping forward aviation in this country. On Monday night, Mr. Sandys, M.P., raised the question of the supply of aeroplanes for the Army, he referring specifically to the intentions of the Government as outlined on July 18th by Colonel Seely, Under-Secretary for War. Continuing, Mr. Sandys said that a further statement from him would now be welcome. Much light had been thrown on the subject by the military manœuvres on the eastern frontier of France, which he (Mr. Sandys) had followed. The impression these left upon the ordinary observer was that the aeroplane was destined to play a very important part in military operations. Information could be obtained by aeroplane reconnaissance which it would be impossible to gain in any other way in military operations.

It was made obvious that any army which in the future went into the field inadequately provided with an efficiently trained air corps and machines of the best type was taking very serious risks indeed. Recently the right hon. gentleman had made a statement on the subject which was unsatisfactory. It was highly desirable that more official encouragement should be given in regard to aviation. The encouragement given by the French Government had greatly helped in enabling France to take the front rank in the matter, and he hoped the most recent statement made by the Under-Secretary for War did not indicate a change of policy.

Colonel Seely in reply said : It would be quite erroneous to suppose that we were going back on the policy I announced in July. We are going forward. We are determined to bring this country up to a proper—indeed, to a high—standard in matters of military aviation.

Almost immediately we shall issue the terms under which officers will be able to obtain the position of Army airmen. Any officer who passes the test and obtains the Aero Club certificate (for which he must attend and pay for aviation classes) will in future receive £75. After he has obtained the certificate he will be attached to the Army Air Battalion to undergo a course of instruction in military aviation, in those branches of aviation which are of special value for military purposes—making out ground from a height, steering a course in the air by the stars or compass, and drawing an accurate map of what the airman has seen. Then the officer will become an Army airman, and will be so described in the Army List. Those officers who have already joined the Air Battalion will receive an extra £25.

After the Army airman has passed all the tests, it is proposed that he should be attached to the Air Battalion periodically for "refresher" courses. From what I have been able to ascertain about flying, I should think these refresher courses would have to be very frequent, in order that they might continue to be able to master this most difficult art. With regard to the number of aeroplanes, it appears that we have far too few. Undoubtedly we have, but the comparison is with France, which is far ahead of the rest of the world. We have all along hung back, because we wanted to obtain the most useful type. We thought we could afford to wait until we could arrive at a better decision as to what was the best type of aeroplane for the Army.

We have at present in the various stages nineteen aeroplanes, but I must admit that one is broken beyond repair, and one is quite out of date. We have been trying all the different types. We have eleven types, seven of which are biplanes and four monoplanes. We have learnt most useful lessons from these different types of airships, and we are now engaged in testing some of the more speedy monoplanes.

We are arriving at a point when we think we see our way to choose what is the best type, first, for teaching people to fly, and, secondly, for the purpose of war, should war unfortunately break out. As soon as the moment for choice comes—and it will come very soon—we propose to purchase an adequate number of aeroplanes, on which a large number of officers who, no doubt, will be forthcoming, will be able to fly.

Army flying is different from civilian flying, and, for war purposes, it is necessary to have a machine for two men, one to steer and the other to observe. Therefore we want a very special type of Army aeroplane. The specifications for the prizes for the Army aeroplane are now practically complete. The only points remaining to be decided are, not only the total amount, but, what is more important, the distribution of the prize-money. I hope that before the end of the present year we shall be able to announce the prize which the War Office and the Admiralty propose to offer for an Army and Navy aeroplane.

In conclusion, the Government fully recognise the immense importance of aerial scouting in war. It has passed beyond conjecture now as to whether aeroplanes can or cannot ascend in all reasonable weathers and observe large numbers of troops. Further, it is vital for any country that has an army to have an aeroplane survey. Both the War Office and the Admiralty have realised the importance of these things, and are working together to provide a really efficient scouting service. The Government will take every step to put the country on a proper footing in regard to this important subject.

Colonel Yate then asked whether it would not be possible, in view of the heavy expense of learning to fly, to increase the sum of £75 to be granted to each officer. He would also like to know what was considered by the Government to be an adequate number of aeroplanes.

Colonel Seely said the present number of nineteen aeroplanes possessed by the Government would be greatly raised ; but he could not give the exact total. They proposed to train at least 100 officers, and non-commissioned officers and men of other ranks would also be trained.

Sir H. Dalziel urged the Government to do their utmost to encourage civilian flyers, and to make it easy for them to give their services to their own country. At the present time they were being tempted by three or four foreign countries, and they should be allowed to offer their services to their own land first.

How France Encourages the Industry.

IN contrast to the way in which the aviation industry is neglected by the Government of this country, it is announced from a usually well-informed quarter that in the French Military Budget for 1912 the expenditure on military aviation will far exceed last year's figure of £320,000. It is stated that one item will be a sum of £28,000, which will be allocated for the remuneration of military aviators.

A Study of Bird Flight

By Dr. E. H. Hankin, M.A. DSc.

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CHAPTER XXXI.—**Steering Movements in Flapping Flight. Flying Foxes.**

ONE might expect, *à priori*, that steering movements in flapping flight would be discovered by a study of the larger birds. But, as I have elsewhere stated, vultures and adjutants never indulge in prolonged flapping flight. Periods of flapping are alternated with periods of gliding. While gliding, steering movements (by wing-tip rotation or wing depressions) can be seen. It appears to me probable that they choose the period of gliding for steering, as a rule, and only in exceptional instances make any steering effort while flapping.

From my description of the position of the wing-tips in flapping flight, it follows that it is unlikely that the wing-tips play any important part in producing steering effects or canting in flapping flight. We may expect that both these functions are carried out by adjustments affecting the whole wing.

In the case of flying foxes (*Pteropus medius*), I have succeeded in discovering steering movements in flapping flight. It will therefore be of interest to describe the flight of these creatures.

I obtained the following measurements from three different specimens of the flying fox:—

	I.	II.	III.
Weight ...	923 grammes	860 grammes	640 grammes
Span	51½ ins.	48½ ins.	44 ins.
Area of one wing	1·21 sq. ft.	·962 sq. ft.	·914 sq. ft.
Width of wing	8½ ins.	8 ins.	8 ins.
Loading ...	·84 lbs. per sq. ft.	·98 lbs. per sq. ft.	·77 lbs. per sq. ft.

The membrane of the wings of these animals is so soft and extensible that it is difficult to be certain how far the wing measurements given above correspond to the size of the wings in actual flight.

A colony of between one and two hundred flying foxes lives, during most of the year, in a garden in Agra known as the Company Garden. During the day-time these animals may be seen hanging head downwards from the branches of a large tree. During September, October and November these bats used to commence their flight in twilight. After flapping and gliding round the tree for a few minutes they used to fly off, flapping, in solitary flight to their feeding grounds. During December and January the whole colony disappeared. In February a few returned, but from then up to the time of writing (April) they do not start until it is almost completely dark, so further details of their mode of flight are no longer to be observed.

The structure of the wing of the bat, as compared to the wing of a bird, is extremely complicated so far as the numbers of muscles present are concerned. Despite the large size of the flying foxes that I dissected I found that the majority of the tendons were scarcely thicker than a bristle.

Most of the muscles have flexing and extending functions. The flying fox has no power of rotating the wing-tip. There is a muscle that can rotate downwards, or turn downwards the middle third of the anterior margin of the wing. This is the part of the anterior margin that is supported by the first two digits and that extends in front of the main bony framework. By turning downwards of this part of the margin the camber can be increased.

There is also a muscle whose action is to bend downwards the outer part of the wing. The bending occurs at the carpal joint, thus producing the appearance of arching that is seen in the flapping flight of this animal.

That there is a general similarity between the flight of flying foxes and the flight of birds is shown by the following extracts from my diary:—

September 24th, 1910. 6.30 p.m.—At Company Garden.—Flying foxes seen clearly to move wings quicker during the up stroke than during the down stroke. This, combined with the arching at the end of the down stroke, causes the illusory appearance of a pause during the beat.

On several occasions a flying fox seen to cease flapping for making a turn (in the horizontal plane). In each case it recommenced flapping immediately it had turned.

A flying fox seen gliding with wings arched. It was seen to check its speed by advancing the wings which were still arched.

Advance of wings on down stroke seen in slow flapping flight.

Flying foxes frequently seen gliding downwards, at a small angle with the horizon, with wings arched, and at moderate speed. On one occasion a flying fox seen to glide downwards but with wings even and dihedrally down. It was gliding down at a small angle with the horizon, and its speed was seen to greatly increase.

September 26th, 1910.—At Company Garden. 6.30.—A flying fox half flapping showed advancing of wings with consequent rotation round transverse axis. This was for checking speed.

A flying fox gliding with wings arched showed increase of arching of one wing for steering.

A flying fox gliding downwards (at a small angle with the horizon) with wings nearly flat showed a whole wing depression for steering.

I have on other occasions seen increase of arching for steering in flapping flight. The wing appears to be more arched at the end of the down stroke on the side to which the bat wishes to go. But it is a question how far this appearance of increased arching is illusory. It is possible that the arching is not increased in amount, but that it lasts longer. But in the case of a flying fox gliding downwards with wings arched, I have noticed that increase of arching was followed by increased rate of loss of height.

As in birds the dihedrally up position is used for causing rotation upwards, as illustrated by the following observations:—

October 2nd, 1910.—At Company Garden. 6.30.—A flying fox when gliding was seen to put wings in slightly dihedrally up position for rotation round transverse axis to check speed before stop flapping.

Flexing with arching seen for checking speed in gliding. In flapping flight increased arching of one wing seen for steering. This was again seen.

On three occasions I formed the impression that the wing is slightly flexed on the down stroke in flapping flight.

Despite a somewhat intimate acquaintance with the flight of vultures, I have only on one or two occasions seen one of these birds make a sudden movement to avoid another. No doubt, owing to their habit of flying together, they are expert in judging the movements of other birds. Flying foxes show no such gregarious habits when flying. They are only together in the air for a few minutes after leaving the tree on which they roost. Hence, despite my comparatively slight acquaintance with these animals, I have very frequently seen them make sudden movements to avoid one another. On one occasion I have seen them apparently in collision in the air. These sudden movements can be seen to result in the beat of the wings being horizontally to and fro. In a few cases only I have seen that this is preceded by rotation round the transverse axis caused by advancing the wings.

I will close my account of flying foxes with the following extract from my diary:—

November 15th, 1910.—At Company Garden.—A flying fox seen gliding with wings arched. Increase of arching was followed by increased rate of descent.

A flying fox gliding with wings that showed a wing depression. This was a very slight movement. (Apparently it was a steering movement.)

Two flying foxes noticed in collision. As a result there appeared to be rotation both of wings and body to check speed.

Flapping seen without arching. Apparently it was half flapping to check speed.

A flying fox seen to advance wings, and rotate round transverse axis. Then it rotated round its dorso-ventral axis. It gave me the impression that the object of this manœuvre was to turn suddenly horizontally. (Each of these two rotations was through about 90°. A more detailed account of a similar proceeding in the case of a cheel will be given in Chapter XXXIV.)

In arching, the posterior margin of the wing seems to go up.

CHAPTER XXXII.—**The Functions of the Tail.**

With regard to the question of the functions of the tail, Lilienthal expresses himself as follows:—

"As compared with the action of the wings, the tail surface of birds has only a very small importance, since the bird flies very nearly as well as before after loss of the whole of the tail feathers. This is the case not only as regards turning upwards and downwards but also as regards steering in the horizontal plane. A sparrow deprived of its tail flies just as adroitly through a lattice as its intact brother."*

* "Der Vogelflug als Grundlage der Fliegekunst," page 72.

In order to discover the functions of the tail of birds, it is necessary to discover exactly in what respects the flight of the tailless bird is defective.

During the cold weather of 1909–10, several cheels were known to me by sight whose tails were more or less mutilated. The tail feathers of one, or, perhaps, two cheels were entirely missing. Another had tail feathers about half an inch long. Another had only a single tail feather which, however, was stripped entirely of its barbs, and which resembled a bristle of about three inches in length. Another had a single tail feather on one side. Another had a single tail feather on each side. Another lacked the whole of the tail feathers of one side of the tail. I propose to refer to these mutilated birds collectively as "tailless cheels." I was so fortunate as to discover the conditions under which their stability is defective.

Elsewhere I have described as "tail jolting" somewhat rapid up and down movements of the furled tail of the cheel, which appear to have to do with maintainance of equilibrium round the transverse axis. I have on rare occasions seen similar movements in the case of the lammergeyer, the black vulture, and the common vulture, usually when gliding in disturbed and stormy winds. Tail jolting movements are shown by tailless cheels, in the sense that the posterior portion of the body may be seen to be jolted up and down. Tailless cheels, under all conditions, at first sight appear to have as much stability round the transverse axis as tailed cheels. Occasionally, however, in irregular winds, they make double-dip movements more energetically than tailed cheels.

The fact that tail jolting as above described occurs in tailless cheels accords with my suggestion that this adjustment acts by altering the position of the centre of gravity and has nothing to do with the pressure of the air on the surface of the tail feathers.

We have now to consider the functions of the expanded tail, when, as we shall see, there is reason for believing that air pressure on the surface of the tail comes into play.

The long axis of the tail is a continuation of the long axis of the body. When the tail is furled, the tail feathers lie close together and parallel to this long axis. When the tail is expanded the tail feathers come apart like the ribs of a lady's fan. The expanded tail can be rotated to and fro round its long axis. It is necessary to discover the meaning of this movement.

So far as I am aware all birds usually expand the tail when settling in a calm or a light wind. In Fig. 20 I have already shown the aspect of the tail of a green parrot when stop flapping. The tail feathers are seen to be widely expanded. When the bird is settling, besides being expanded, the tail is depressed so that its surface lies nearly at right angles to the direction of movement of the bird. For instance:—

June 17th, 1910.—At Ballia Ravine. 2.46.—A crow seen descending. Its tail was furled and raised. Immediately before perching it expanded and depressed its tail.

A tailless parrot is known to me by sight. When in flapping flight in company with other parrots it shows no lack of stability or of power of guiding its movements. On one occasion I happened to see it perching. As it caught hold of the bough with its feet it seemed nearly to tumble over backwards; that is to say, there was too much rotation round the transverse axis.

These facts suggest that, in perching, the expanded tail acts as a brake, principally for checking movement round the transverse axis. Rotation round this axis is produced by advancing the wings, and checked by expansion of the tail. The depressing of the expanded tail may also help to check the forward movement of the bird through the air.

Expansion of the tail, in the case of pigeons and swifts, is used to assist in checking speed in gliding flight. For this purpose the wings may be seen to be placed dihedrally upwards. In some cases the dihedral angle may be nearly as much as 45°. This adjustment tends to produce rotation upwards round the transverse axis. The expansion of the tail tends to check this rotation. The two actions, together with the decrease in supporting area of the wings, result in a decrease of speed.

We have now to consider the function of the tail in relation to stability round the dorso-ventral axis.

In a light wind, and away from the influence of currents directed upwards from high buildings, tailless cheels show no lack of stability round the dorso-ventral axis.

In a light wind, but in the presence of upwardly-directed currents, tailless cheels show very slight instability round the dorso-ventral axis. For instance:—

May 29th, 1910.—On Strand Road outside and below Fort battlements. From 6.30 p.m. onwards.—Wind east, for the most part light, just moving leaves. Many cheels and one or two scavengers over the battlements. Tailless and short-tailed cheels all appeared nearly stable round dorso-ventral axis. Cheels kept their tails furled except sometimes when gliding low just over battlements and when gliding to leeward. When just above battlements the tailless cheels seemed unsteady round dorso-ventral axis. During a light puff of wind many cheels remained wind-facing almost fixed in position. Others, and also the tailless cheels glided to and fro above the battlements at right angles to wind direction. At the end of their course the tailless cheels turned just as easily as the others, using wing depressions.

Both cheels and scavengers were noticed to increase flexing of wings to increase speed, *e.g.*, one cheel chasing another, a cheel chasing a hawk, or in response to a puff of wind.

As the wind was easy, tailless cheels were able to glide up to the front of the group of birds. This was noticed three times at least. When directly overhead slight instability round the dorso-ventral axis was noticed. During a puff of wind, when wings were much flexed, a tailless cheel appeared to have alulae extended. (I believe this adjustment might, under similar conditions, be shown by a complete cheel.)

Tailless cheels appeared to make double dips, when wind-facing more often then complete cheels. Except for slight tail-jolting, tailless cheels were quite stable when going to leeward on a curved course.

All the cheels went away between 7.10 and 7.16, when it was getting dark.

On the other hand in a stronger wind over the fort battlements tailless cheels show instability round the dorso-ventral axis. This is especially the case when the wind is west. Owing to the arrangement of buildings on the west side of the fort, a westerly wind causes complicated and varying upward currents. For instance:—

May 7th, 1910.—At Delhi Gate of Fort. At 5.45.—Wind west and rather strong. Many cheels and scavengers wind-facing. A tailless cheel showed unsteadiness round dorso-ventral axis. A depression of the wing for turning seemed to produce more steering (in the horizontal plane) than was intended. Hence the bird had to go off on a glide to leeward. It was unable to advance as far in front of the battlements as complete cheels when wind-facing. A cheel with only one tail feather was similarly unsteady.

I have seen the same phenomena on other occasions. If there is a wind, cheels collect on the windward side of the walls of the fort as the air becomes unsoarable at sunset. If the wind is strong, the birds form a column reaching upward for 100 metres or perhaps more above the battlements. If the wind is light, the cheels remain at a lower level, gliding just over the top of the battlements. When the wind is west and strong, complicated air currents occur, and cheels appear to find gliding under these conditions to be a difficult task. Steering movements of the wings, jolting and rotation of the tail, all occur with bewildering frequency. Especially in a stronger wind tailless cheels may be seen generally on the leeward side of the cluster of birds. Any wing depression for steering seems apt to turn them too far. They may try to correct this excessive turn by a depression of the other wing. Sometimes they succeed, but more often they turn too far in the opposite direction, and appear obliged, as if against their will, to glide off to leeward. Normal cheels, on the other hand, supported on the ascending currents, often glide to some distance to windward of the battlements. Here they may remain for several minutes at a time "wind-facing." That is to say, they remain, generally facing the wind more or less, gliding to and fro, and so adjusting their speed that they travel but slowly over the earth, and remain at almost a constant distance to windward of the battlements. Sooner or later they are turned, as if by some irregularity of the wind, and glide rapidly to leeward. Then, turning, they glide up again to windward, and reach their original position. Tailless cheels are evidently handicapped in attempting this feat. Usually they have scarcely crossed the line of the battlements when they may be seen to be in difficulties, and after a few energetic attempts to remain facing the wind, they may be seen to turn away, and glide off to leeward.

When at some height above the battlements cheels usually keep their tails furled. When nearer the battlements the tails are more or less expanded. As a rule the tail is fully expanded when the bird is making a turn, or when it is gliding away to leeward. The tail when expanded is frequently rotated to and fro round its longitudinal axis. That is to say, first one side and then the other side of the tail is depressed below the horizontal plane. The range of movement of the tail in this rotation may be as much as 30°. There is no clear and evident connection between rotation of the tail and change of course. Sometimes a cheel may be seen with its tail strongly depressed to one side for an appreciable time, but yet the bird continues to glide in a straight line. That is to say, a depression of one side of the tail *per se* has no steering action. Sometimes after the tail is depressed on one side there is a wing depression of the same side, to which side the cheel is accordingly steered. If this sometimes occurred, and if the alternative was that during a steering movement the tail should be horizontal, one might come to the conclusion that a depression of one side of the tail (that is to say, a rotation round its long axis) was an additional movement that aids steering but that is not indispensable. But it sometimes happens that, during a turn, the tail is

observed to have been rotated in the opposite direction. For instance, a wing depression of the left wing may occur and steer the bird to the left at a time when the right side of the tail is depressed.

As soon as my acquaintance with the facts led me to doubt whether rotations of the tail produce steering movements, I made a point of looking to see whether, in normal turns, the depressing of the side of the tail was coincident with or preceded the wing depression. To my surprise I found that the rotation of the tail, if it occurred at all, preceded the wing depression. In view of the facts described relating to tailless cheels, there can be little doubt that the function of the tail is to act as a break for turns round the dorso-ventral axis, and that it does so more efficiently if the side of the tail is depressed on the side of the turn. Supposing the bird is about to steer to the right, this steering tends to be checked by the tail if this organ has so rotated round its longitudinal axis that the right half of the tail is depressed below the horizontal plane.

Obviously if movements of the tail produced steering, then tailless cheels should turn less readily than complete cheels. But, as we have seen, the contrary is the case. Hence the dorso-ventral axis instability of tailless cheels gives strong support to the view that the function of the tail is to act as a break in the manner described.

The numerous apparently purposeless rotations of the tail when cheels are manœuvring in complicated air currents must on this view be regarded as "anticipatory movements." They are preparations for turns that it may or may not make as it is influenced by changing air currents or the necessity of avoiding other birds.

Flying foxes when poising before perching may frequently be seen to advance the hind legs. No doubt this movement is preparatory to grasping the bough with their feet. But as it results in bringing the posterior part of the wing surface to a position at right angles to the direction in which the animal has been gliding, it is possible that to some small extent the action has a braking effect similar to that produced by the depressed and expanded tail of birds when perching.

It remains to consider the possibility that the tail has an action similar to the horizontal rudder of aeroplanes in steering the bird up and down. I have already stated that the tailless cheel, in an irreglar wind, may show double dips more often than complete cheels. This statement is illustrated by the following observation:—

December 13th, 1910. At 11.20.—Wind rather strong and moving branches. A tailless cheel seen overhead about 10 metres above the tree-tops. It showed slight instability round the dorso-ventral axis. This consisted in occasional sudden turns (round this axis) through about 10°. Each time it turned back to its original position with equal suddenness and after an appreciable pause. There was no attempt to check rotation round the dorso-ventral axis by double dips. It made double dips more often than did complete cheels that were gliding near. Its double dips seemed larger and more sudden than usual.

Though double dips were not used to check rotation round the dorso-ventral axis, it is possible, on the one hand, that such rotations caused loss of speed ahead, and hence there was the necessity for an occasional double dip to increase speed. On the other hand, it is possible that the surface of the expanded tail of the complete cheel acts, so to speak, passively in checking rotation round the transverse axis. Possibly, lacking this break, the tailless cheel is apt to be rotated upwards round the transverse axis, and hence occasionally finds it necessary to make a downward rotation round this axis by means of a double dip. But, on the other hand, there is no doubt that the tail does not actively produce rotation round the transverse axis after the manner of the horizontal rudder of an aeroplane. If it did so, the tail should be depressed when the bird is gliding downwards. But, as we have seen, when the bird is gliding downwards the tail is furled and raised. It then acts by raising the position of the centre of gravity relatively to the centre of resistance of the wing-tips, thus tending to cause rotation downwards round the transverse axis. Conversely, when the bird is perching, it rotates upwards round its transverse axis. If the tail acted as the horizontal rudder of an aeroplane, it should then be elevated; but, as we have seen, the expanded tail of the perching bird is depressed.

(To be continued.)

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THE MILITARY AEROPLANE.

IN the October issue of the *Army Review*, Major Sir A. Bannerman, Bart., R.E., commanding the Air Battalion, has an interesting article, in which he sets forth a few of the things which should be borne in mind by the designer of an aeroplane for military work. He summarises the broad outlines of the requirements to be met by air-craft for use in the British Army as follows:—"Airships must be small and speedy. Aeroplanes must be readily dismountable, not too large, have speed enough to allow of flying in moderate winds, be able to land on rough ground, and start from it, and need but little run for starting. The settlement of details, such as loads to be carried, speed of ascent, duration of flight, &c., falls within the province of practical military flyers, who hold very various opinions."

With regard to the use of aeroplanes, the author points out that, although damage to important points may occasionally be done by dropping explosives from aeroplanes, it is impossible to take the prospect seriously; air-craft may be so useful in other ways that a commander can really be justified in risking their loss by using them for offensive purposes. There remain the two functions of despatch carrying and reconnaisance, and, as for the latter a passenger must be carried, it should be possible to design one type to suit both cases. A wireless telegraphy installation will probably form part of the equipment in the future.

Standardization of parts is essential to war material, therefore there should be as few varieties of aeroplanes as possible. With regard to arrangements for aeroplanes in actual service, Major Bannerman suggests that it appears advisable to group aeroplanes in pairs so that at least one should always be available. Two pairs could be combined to form a section, and two or more sections made into a company, but it is important that each section should contain machines of only one type, as by that means the expert supervision is simplified and personnel reduced. One of the most difficult problems is the repair and maintenance of aeroplanes in the field. Some form of mobile workshop must be maintained close to the front, otherwise it may be necessary to abandon machines that have only slight defects.

With regard to the airship, it has been proved that large vessels are unsuitable for use in this country owing to the numerous trees, woods, towns and villages, combined with a strength and gustiness of winds. The exact size most suitable for the British Army can only be found by experiments, but it seems that the gas capacity should be between 80,000 and 100,000 cub. ft. One of the chief difficulties in dealing with airships is the establishment required to maintain them. Sixty men are needed to handle a vessel of moderate size, while the gas to keep it properly inflated means much heavy transport.

In concluding the article Major Bannerman points out that the kite is by no means superseded in military operations. He also draws attention to the fact that officers for aerial work are much rarer than is supposed, and as the work is peculiarly trying, few individuals long retain a taste for it. The remedy must be to induce larger numbers to take up the duties and consequently to replace the elder hands by fresh recruits. Far more candidates are available than are required; it remains only to give them a chance for showing what they can do.

We are reminded that Great Britain's frontier is the enemy's coast, and the moment he puts to sea we are invaded. That being so, it follows that large aerial stations in the interior of England, or even near the coast, cannot be so effective as those in the frontier fortresses of Continental Powers. They may be suitable for passive defence, but their distance from the enemy will make it very uneconomical, if not impossible, to use them as points of departure for air-craft intended to operate overseas. It is therefore obvious that, although we have much to learn about aerial work from our neighbours, it will not be safe for us blindly to follow their lead.

The main lines of a British defensive policy must be decided by the needs of the Navy, and, unfortunately, little is as yet known about the use of air-craft in connection with Naval forces. Developments are likely to take place during the next two or three years, and by the end of that period we should know definitely what are the offensive and defensive powers of dirigible balloons and aeroplanes, respectively; then it will be possible to come to some decision as to the class of air-craft to be employed, and the size and position of the stations to be formed.

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Death of J. J. Montgomery.

WE regret having to record the death of Prof. John J. Montgomery, of California, which took place while he was experimenting with his gliders at Santa Clara. One of the earliest practical workers, and also one of the closest students of the science, Mr. Montgomery was, perhaps, best known to the public through the experiments made with his Langley type gliders by Maloney, who launched himself into the air on these machines after ascending with them attached to a balloon.

A Study of Bird Flight

By Dr. E. H. Hankin. M.A. DSc.

CHAPTER XXXIII.—Various Modes of Descent. Rapid turns round the Dorso-Ventral Axis.

IT has been shown that a bird, when in ordinary gliding flight, may steer from side to side by rotating the wing tip. This procedure checks the speed ahead of the wing whose tip is rotated, which thereupon becomes the inside wing during the turn. As it is probable that this check has to do with a diminution of the angle of incidence (with maintenance of camber), one would not expect this method of steering to be operative when the bird has no speed ahead. Nevertheless when the bird has no speed ahead, that is to say, when it is dropping feet foremost through the air, it has the power of making extremely rapid turns round the dorso-ventral axis, which power it does not seem to possess under ordinary conditions of flight with speed ahead. Facts to be described in the present and the next succeeding chapters will be found to explain these rotations.

If a vulture comes to earth by metacarpal descent, speed ahead decreases. In carpal descent the bird is falling feet foremost through the air, and there is almost certainly no increase of speed. But if a vulture descends in a strong wind, it may require to maintain or increase its speed ahead. For this purpose it descends by a method that I propose to call "shoulder descent," as the wing is retired by movement at the shoulder-joint. At the moment of change from ease-gliding, for instance, to shoulder descent, a small rotation round the transverse axle may be seen to occur. That is to say, the centre of lifting effort of the wing is brought backwards by the retirement. A couple thereby originates between the "lift" and the "weight." This couple causes rotation round the transverse axis until the centre of lifting effort regains its normal position vertically above the centre of gravity. Flexing also occurs at the elbow joint. This movement (as shown in Chapter XXIII) only causes slight diminution of camber. There is little or no flexing at the carpal joint. That is to say, the anterior margin of the wing tip remains in its normal position at right angles to the line of flight, and consequently air continues to impinge on the under surface of the wing tips, and steering from side to side takes place by wing-tip rotation.

Shoulder descent is the mode of descent usually employed by the smaller birds when coming down from a height. In this form of descent the wings may be dihedrally down (parrots, mynas) leading to a decrease in the angle of incidence and increase of speed, or flat as in vultures, or rarely dihedrally up. I have seen descent with wings retired and dihedrally up in a pigeon. This was probably a mode of decreasing speed. I have also seen a large swallow-tail butterfly (*Papilio ravana*) glide downwards at a small angle with the horizon with front wings retired and dihedrally up. If this butterfly wishes to descend more rapidly it places its wings at a dihedrally angle approaching 45°, and then drops feet foremost through the air. It checks its fall by decreasing the dihedral angle.

When near the ground, scavengers, crows, and smaller birds frequently check speed by increasing the angle of incidence above the normal. To do this the bird advances its wings. This causes rotation round the transverse axis until the "lift" is again vertically above the "weight," thereby increasing the angle of incidence. The bird is not appreciably deflected from its course by this procedure. It continues to travel ahead, but with diminishing speed. A crow having thus checked its speed, to some extent, may bring itself to a full stop by a further advancing of its wings with further consequent rotation round the transverse axis. It then drops vertically downwards, through a distance of one or two feet, on to its perch. This clumsy mode of descent is in strong contrast to the graceful movement of the vulture, which always glides to its perch without any sudden change of course.

From its similarity to stop-flapping, this mode of checking speed may conveniently be described as "stop descent."

I will now quote cases of carpal descent, in which it will be seen sudden rotations round the dorso-ventral axis not infrequently occur.

June 15th, 1910.—Naini Tal Lake. At 4 p.m.—A cheel noticed in a strong wind descending with legs hanging down, and the plane of its wings horizontal. It was facing the wind and descending vertically. The wings were flexed to a greater extent than occurs in flex-gliding. The tail was furled and directed upwards. Twice at least a forward extension of the alulae was observed. Towards the end of the descent (when within 3 ft. of the surface of the lake, and near some overhanging trees) the cheel was seen to turn suddenly in the horizontal plane through an angle of about 90°. That is to say, the bird rotated round its dorso-ventral axis without canting. After an appreciable pause (a small fraction of a second) it turned with equal suddenness back to its original direction.

June 22nd, 1910.—At Ballia Ravine. 4.37 p.m.—A brown vulture gliding overhead flexed its wings more than usual. It began to descend vertically with legs hanging down, and losing speed ahead. Then it expanded its wings, and, for an appreciable interval, appeared to remain motionless in the air. Then it gathered speed ahead. Then, flexing its wings with secondaries taut (*i.e.*, metacarpal descent), it descended in the usual spiral, steering by dip movements. When near its perch, drop turns with small rotations round the dorso-ventral axis were noticed. When still nearer its perch the alulae were seen to be extended.

June 30th, 1910.—Ballia Ravine. 3.50.—A vulture seen descending from a great height vertically. Its wings were strongly flexed and flat. They were in the horizontal plane. That is to say, the bird was dropping through the air feet foremost. The alulae were extended and in motion. Probably, while so descending, the vulture was in a strong wind. After descending for some distance in this way, it extended its wings, not fully, but to the usual position (for metacarpal descent); then it lowered its legs and continued its descent by the ordinary method.

December 18th, 1910.—On Tundla Road beyond Jharna Nullah. 11.30.—A strong east wind. An eagle seen in carpal descent from a height. It descended nearly vertically, and perched on a tree. It began to lower its legs when about 20 metres above its perch. The alulae were clearly seen to be strongly advanced during the whole of the descent, but they were not in motion. The tail was expanded. The bird showed slight instability round the longitudinal axis after the legs had been dropped.

The question arises, what is the object of advancing the alulae during carpal descent? The last case described suggests that the purpose of the movement is to bring more supporting area in front of the level of the centre of gravity without increase of span. There can be no doubt that the advancing of the alulae must alter, to a slight degree, the position of the centre of lifting effort of the wings as a whole, and so may play a part in maintaining equilibrium round the transverse axis.

It will be obvious from the above description that it may be difficult in some cases to distinguish between carpal and shoulder descent by observation. For instance:—

June 27th, 1911.—Ballia Ravine. At 9.53.—A vulture seen ease-gliding. The white feathers of the underside of the wing appeared yellowish-green. It changed to metacarpal descent, and appeared white. Then, giving a dorsal view, it changed to carpal descent. The centrally-placed secondaries could then be seen to be in slight flickering up-and-down movement. The range of movement may have been half an inch. This may be regarded as a proof that in carpal descent the angle of incidence is zero.

There is room for doubt as to what happened in this case. My recollection is definitely that at the time when the secondaries were flickering the bird had ample speed ahead, and was not noticeably dropping feet foremost. It is possible that after the metacarpal descent there was a short period of shoulder descent, in which the angle of incidence is maintained, and that this was followed by carpal descent, with no angle of incidence, and in which, therefore,

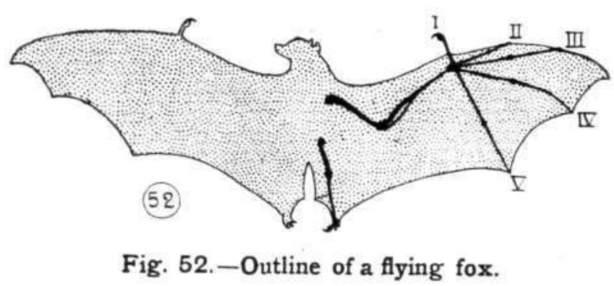

Fig. 52.—Outline of a flying fox.

the feathers were free to move up and down like a flag shaking in the wind. Other possibilities may be suggested. It is not a point on which a definite opinion can be formed.

The following is another similar observation :—

August 5th, 1911.—Jharna Nullah, at 5.50.—A vulture flex-gliding downwards, with speed ahead, in a strong wind, with legs dropped. Shaking of some of its feathers was seen. I could not recognise which, as the wind was moving my binocular.

In the first quoted case of carpal descent, the bird showed a sudden turn round the dorso-ventral axis. This, as usual in carpal descent, occurred while the bird was in a strong wind. Similar turns while the bird is falling through the air feet foremost may be seen in absence of wind. For instance :—

June 10th, 1910.—At Bailia Ravine, at 4.0 p.m.—Some cheels ease-gliding in a limited and sheltered place between rocks and trees were seen making flat turns (that is to say, turns without canting). The birds were gliding downwards with wings strongly exed. They seemed to turn on their dorso-ventral axes instan-

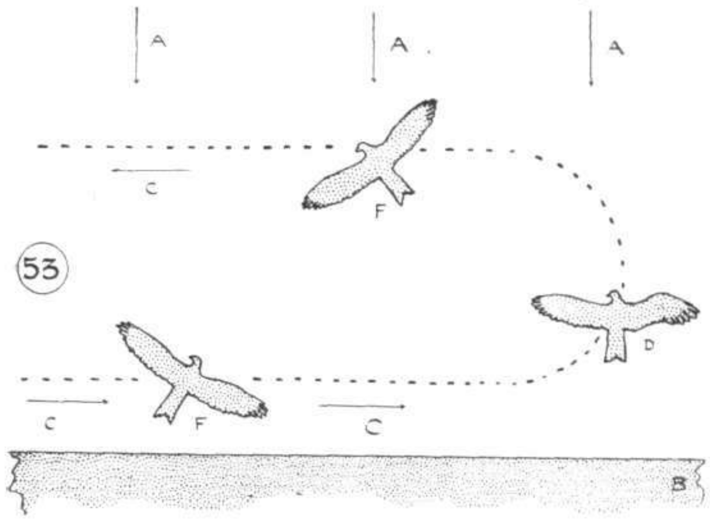

Fig. 53.—Diagram showing cheel turning in an ascending current of air. A, A, A, wind direction. The wind, on striking the wall of the shed, B, is deflected upwards. C, C, C, direction of gliding flight of the cheel. At D the outside wing is shown flexed and advanced. For the sake of clearness the cheel is represented as making a gain to windward during the turn. This did not occur. The cheel turned on its dorso-ventral axis (or nearly so) and returned approximately along the track on which it came.

taneously. Cheel after cheel was seen making this turn in the same part of the ravine, or rather in a cleft in the rock. It was impossible to see the movement by which the rotation was brought about. The amount of turn must have been nearly 180°. The cheels made these turns in a sheltered place, but a light wind was blowing up the main ravine.

In the following chapter I propose to describe the movements of cheels when gliding in an ascending current of air. It will be seen to be possible to make a suggestion as to the nature of the adjustment by which such sudden rotations are produced.

CHAPTER XXXIV.—Gliding in an Ascending Current.

In previous chapters I have mentioned the behaviour of cheels when gliding in an ascending current over the battlements of the Agra Fort. I now propose to describe this form of flight more minutely.

Before describing what I have observed, it will be convenient to describe briefly what one might expect to observe.

Let us consider the case of a bird gliding horizontally in unsoarable air. There is a small angle of incidence. Consequently the centre of pressure of the air on the wing does not coincide with the centre of area. As is well known, it is somewhere between this point and the anterior margin. The smaller the angle of incidence the nearer it is to the anterior margin. In this form of flight the bird keeps its wings "straight," that is to say, neither advanced or retired. When the wings are in this position the centre of lifting effort, or briefly "lift," is at a point vertically above the centre of gravity.

Now let us imagine the case of a bird supported on a vertically ascending current of air. Let us suppose further that it is not gliding ahead. We may imagine the wings to be spread out horizontally. The air exerts pressure on the under side of the wing at right angles to their surface. That is to say, the angle of incidence is 90°. Therefore the centre of pressure must coincide with the centre of area. If the wings were in the "straight" position, as in the first case, the centre of pressure would be at a point some way behind the centre of gravity. Therefore there would be a couple between the "lift" and the "weight" which would rotate the bird downwards round its transverse axis. That is to say, if the bird wishes to regain horizontal, it must advance its wings.

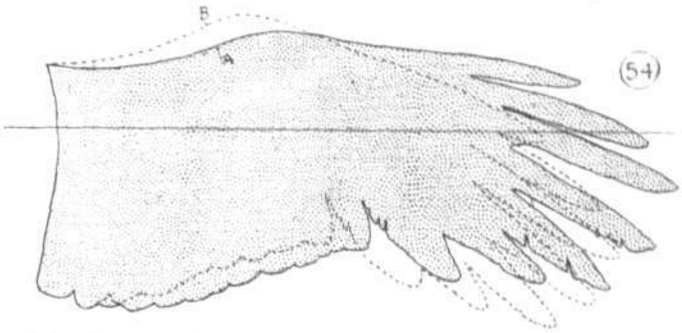

Fig. 54.—Outlines of wing of a cheel. At A when slow flex-gliding. At B when medium speed flex-gliding. The horizontal line shows the level of the centre of gravity.

Now let us consider what the bird must do if it wishes to take advantage of the ascending current to produce speed ahead. It would flex the wings at the carpal-joint. Thereby, as already shown, the secondaries would be relaxed, and the free or hind ends of the secondary quills would be pressed upwards by the air. The effect is shown in Fig. 55 at B. The ascending current would be deflected, as shown by the arrows. The resulting force of reaction would then drive the bird ahead.

We may now consider the actual facts of observation. The above-described disposition of the wings is seen when the bird wishes to make speed ahead. But usually the bird wishes to remain in the ascending current more or less at one spot, or it glides along the battlements, heading in a direction of perhaps 45° or more from the wind direction. Further, the current does not ascend vertically, but rises at varying angles with the horizon. Hence the wings are usually held somewhat advanced, with the wing-tips slightly retired. That is to say, it is probable that there is a decrease of camber (as compared with the disposition for circling), and also a decrease of the angle made by the wing with the horizon. But the exact disposition of the wings varies rapidly with the varying currents, and is difficult to see.

Should the wind freshen, relaxation of the secondaries at once occurs in order to increase speed ahead, and thereby keep the bird in its position over the battlements. In the following instances the bird at once took advantage of the ascending current to aid it in travelling up wind.

August 10th, 1911.—At 6.33.—In a gust of wind a cheel lee-looping and flap-gliding up wind. As it came into the ascending current reflected upwards from the house, it retired the wing-tips and relaxed secondaries. As soon as it got beyond the influence of the ascending current, it tightened its secondaries, and glided with wings slightly arched, with loss of height, and settled as the gust of wind died away.

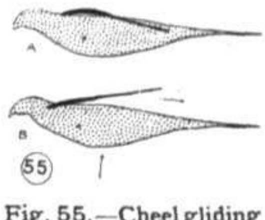

Fig. 55.—Cheel gliding in an ascending current of air at moment of turn. A shows disposition of the inside wing. B shows disposition of central portion of outside wing. The reflection of the air current by this part of the wing is indicated by arrows. The dot in each figure shows the position of the centre of gravity.

August 27th, 1911. At 6.57.—Wind moving small branches. A cheel flap-gliding up wind. It glided over the house at a height of about 4 metres above it. When it reached the ascending current reflected by the windward side of the house, it relaxed its secondaries. As soon as it was beyond this current, it flapped. In the next period of gliding, it had secondaries taut and wings slightly arched.

7.25.—A cheel gliding up wind during a lull, passed over the house showing no relaxation of secondaries. (That is to say, relaxation of secondaries only occurred when there was an ascending current.)

The following observation gives a clue to the probable method employed for steering when in an ascending current :—

April 15th, 1911. At Jharna Nullah. 5.50.—Some cheels wind-facing in an upward current of air on the windward side of

a shed. In several cases, when turning (in the horizontal plane) opposite the end of the shed, they advanced the outside wing flexing it at the same time. The advancing must have been as much as an inch at the carpal joint. The wing tip was retired through, perhaps, two or three inches. The turn was gradual, but the advancing was a sudden movement. The upward current was only just strong enough to support the cheels at about 2 metres height above the shed. It was not strong enough to support scavenger vultures. Some of these were near in flapping flight, and others were settled.

It is necessary to consider in detail what happened in the above case. Fig. 53 shows diagrammatically the movements of the bird. Fig. 54 shows the outline of the outside wing before and after the flexing. It is probable that the flexing of the outside wing caused it to assume the slow or medium flex-gliding position. Fig. 55 shows diagrammatically the probable sections taken at about the central parts of the two wings during the movement in question. For the sake of clearness, the probable amount of difference in the disposition of the two wings has been exaggerated in the drawing. The inside wing is shown at, A. It is cambered, but not so much so as in circling. The outside wing is represented at, B. Owing to the flexing the secondaries are relaxed, so that the posterior margin of the inner part of the wing forms a curved line with the convexity upwards. Hence, though the greater part of the outside wing is flat or slightly cambered, the secondaries of the central part of the wing are relaxed. That is to say, their free ends are directed upwards. Hence the ascending current of air striking this part of the wing is reflected, as shown by the arrows, and in being reflected tends to drive ahead the wing in question.

So much for the facts. My supposition as to what actually occurred is this. The cheel, having speed ahead, commenced its turn by a depression of the inside wing or wing tip (which was not observed). The speed ahead having been abolished by this turn in the horizontal plane, and the cheel being supported in the ascending current of air, it relaxed the secondaries of the outside wing to obtain an additional steering effect. Probably this relaxation of the outside wing (which was only visible for a fraction of a second) was followed by slight extension of the same wing, and then relaxation of the inside wing. Thus both wings would acquire the same disposition. This adjustment would tend to check the rotation and to produce speed ahead.

Obviously, this relaxation of the secondaries of the two wings to different extents may be the means employed of producing rapid turns round the dorso-ventral axis, such as occur when the bird is falling feet foremost through the air. I have seen a cheel make such a turn, amounting to 360°, when in a sheltered place and when having no speed ahead. Obviously, such a turn could not have been caused, under the circumstances, by wing-tip rotation. It could have been caused by unequal relaxation of the secondaries of the two wings.

Hence it appears that birds have two methods of steering in the horizontal plane, one for use when there is speed ahead, the other suitable for use when there is speed foremost, but no speed ahead. One method acts by checking speed of the inside wing. The other method acts by giving speed to the outside wing.

Certain somewhat obscure movements of the outside wing-tip in circling have been described elsewhere. These movements obviously resemble a steering adjustment of the second kind. These movements most commonly occur at the end of the windward side of the track, and when speed is about to increase for the downwind side. That is to say, at this point of the track, the outside wing of the circling bird behaves as if it were in an ascending current of air.

There is a certain similarity between slow flex-gliding and gliding in an ascending current, which it will be of interest to consider. It is a matter of easy and certain observation that in fast flex-gliding the secondaries are so far relaxed that the camber is abolished and the angle of incidence is negative. Suppose a line is drawn horizontally backwards from the front edge of the wing, then the free or hinder edge of the wing does not lie below it as in ordinary gliding. It lies above it. That is to say, the plane of the wing makes an angle with this horizontal line. The angle may be about 20°.

Observation makes it probable that in slow flex-gliding there is a small negative angle of incidence of this nature. Also the camber is nearly, if not quite, abolished. The wings are less advanced than in fast flex-gliding. Therefore, in slow flex-gliding, and in no other form of soaring flight, the wings assume a disposition that appears identical with that assumed for gliding at speed in an ascending current.

This similarity between slow flex gliding and gliding in an ascending current makes it probable that steering in flex-gliding flight is not arrived at by dip movements, but by varying the amount of relaxation of the secondaries of the two wings. The only actual observation I can quote bearing on this point is the following :—

May 18th, 1911. At 7.30.—Stormy west wind moving branches. Dust in air. No heat eddies. Cheels circling.

9.0.—A cheel slow flex-gliding in stormy soarable wind, steered by tightening inside wing secondaries.

I have never seen any indication of dip movements—that is to say, rotation of wing tips in flex-gliding. I have a vague recollection of seeing steering by slow depression of the inside wing in this form of flight, but can find no mention of this in my diary. It is a matter that should be settled by observation rather than by inference. I shall refer again to the position of the wing tips in flex-gliding in a later chapter. (*To be continued.*)

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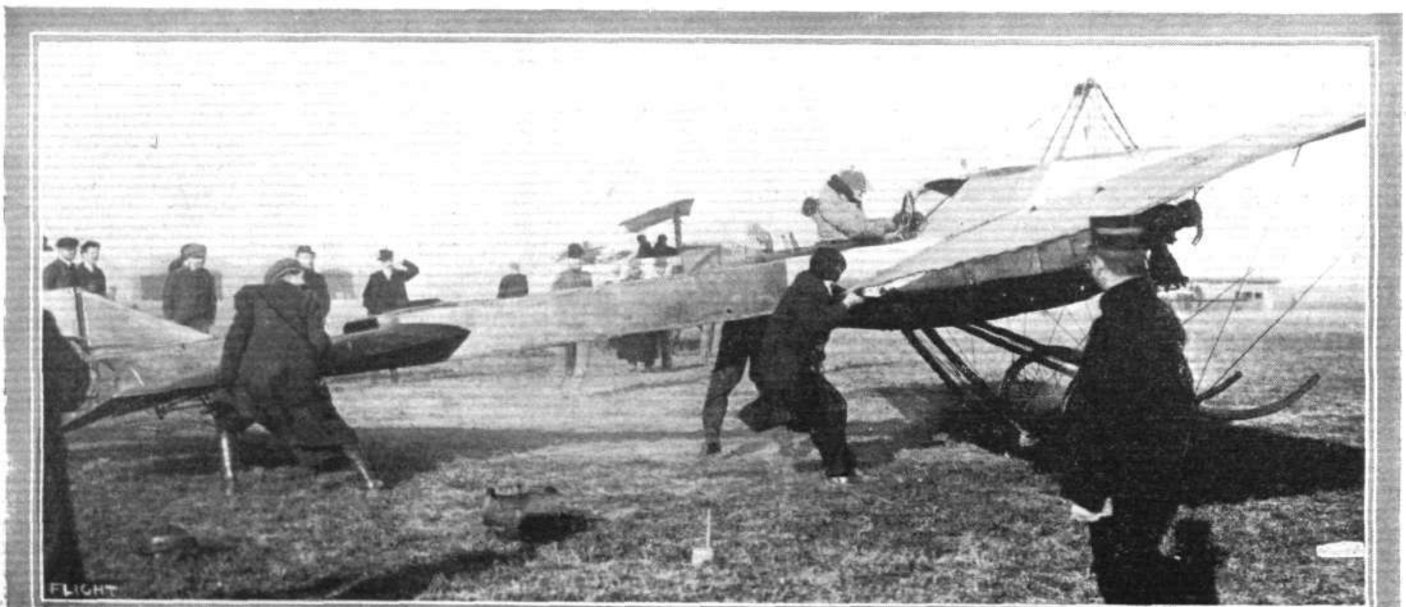
Aeroplanes in War.

THE Italian Army in Tripoli are now using three Blériot monoplanes which have been in use in Italy for some time, one of them being flown by Captain Piazza, who is the Commander of the Aviation Section, and who will be remembered as being the winner of the Italian Circuit during last summer (Bologne-Venise-Rimini and Bologne). The Italian Government has placed a further order for three more Blériot monoplanes, and Captain Anostini is now at Etampes to see the trials of the machines, which are to be delivered this week.



Vedrines, on a Deperdussin monoplane, just receiving the signal to depart for the long flight test in connection with the military competition at Rheims.

A Study of Bird Flight

By Dr. E. H. Hankin, M.A. DSc.

CHAPTER XXXV.—Lateral Stability.

AN important part of the control of an aeroplane is the means adopted for ensuring lateral stability. The question arises as to the nature of the method employed by birds for subserving this important adjunct to their powers of flight. I have seen a cheel gliding through the open doorway of a racket court. The doorway was too narrow for the expanded wings of the bird. As it reached the door, it smoothly and evenly canted itself over, glided through in this canted position, and then, when on the other side, presumably returned with equal smoothness to a level keel. I believe it is the perfection of the method employed by birds for thus canting to one side or the other that has prevented my discovering its nature with certainty by direct observation. Some facts to be described in the present chapter will, however, enable us to draw an inference as to the nature of the adjustment.

I have already proved that lateral stability is not due to rotation of the wing tips in opposite directions. It is conceivable that lateral stability might be maintained by rotation of the wings themselves in opposite directions. But it is not likely that birds would employ an adjustment in which both wings would be so placed as to tend to check speed ahead, and in which the lifting efficiency of both wings would be diminished. Further, such a suggestion is not supported by any facts of observation. It is possible to observe wing rotation. For instance, I recently saw a cheel, for a fraction of a second, rapidly rotate its wings to and fro, to a very small extent round their long axes. This happened while the bird was gliding and about to perch. Probably the movement was anticipatory to stop flapping, in which, as elsewhere proved, rotation of the wings occurs or can occur. Also the movement that I have described as "wing depression" has been shown to be due to wing rotation lasting slightly longer than in this instance.

That cheels can catch food thrown to them while they are gliding in the air, and that they always catch the food with their feet, never with their beaks, are well-known facts. The details of the extremely rapid movements by which they accomplish this feat are very difficult to observe. The fact that one can hardly help feeling amusement or astonishment at the agility of the bird adds to the difficulty of making the observation. It is my experience that the power of minute observation is greatly diminished if the consciousness is occupied by any feeling, whether of surprise, interest, or pleasure.

On one occasion I was able to follow the movements of cheels while catching food in the air. I was throwing pieces of bread to cheels from the terrace outside my house. This terrace has a height of about 15 ft. from the ground. If the cheels were gliding in front of me, they had to make a sudden turn and a dive in order to catch the bread. This happened at first. Then, as if the cheels knew what I was doing, they kept gliding in the air behind me, so that on swooping they travelled in the same direction as the piece of bread, and could catch it more easily. An example of catching a piece of bread after a difficult turn is the following:—

October 13th, 1910.—At 4.15.—A cheel was gliding past in front of me about 5 ft. above my level as I threw a piece of bread. When the cheel had reached a point about 10 ft. to the left of the position where the piece of bread was falling, it rotated round its transverse axis through about 90°. At the end of this rotation the longitudinal axis of the bird was vertical instead of being horizontal. That is to say, the beak pointed vertically upwards and the tail downwards. Then the cheel rotated through 180° round its dorso-ventral axis. That is to say, after making this second rotation, its beak pointed downwards and its tail upwards. This movement was quicker than the transverse-axis rotation. I could see that the wings were flexed during this second rotation. While it was making these rotations a small feather dropped off. The cheel then swooped downwards, and caught the falling piece of bread at a time when the latter had reached a point about 2 ft. from the ground. While swooping the wings were flexed and there was no flapping. As usual, the cheel caught the bread in its claws, not in its beak. The rotation round the transverse axis was presumably due to advancing of the wings, as observed in other cases. At the moment of catching the bread the cheel began gliding upwards (in a curve of long radius). As observed in other cases, this gradual change of course must have been due to placing the wings in the dihedrally-up position. The bird glided upwards, and about its original height. Then, as usually occurs, the claws were brought forward and the head bent down and backwards, as the bird eat the bread without interruption of its gliding flight. (*See* Fig. 56.)

In the above account I have described two methods of producing rotation round the transverse axis. The first, by advancing the wings, causes a sudden rotation and is associated with loss of speed ahead. That is to say, speed ahead is changed into speed feet foremost. This feet-foremost speed obviously was the source of the energy used for rotation round the dorso-ventral axis, and also was a part source of the energy required for the swoop, whose speed was greater than could be accounted for by gravity alone. The second method of producing rotation round the transverse axis was by placing the wings in a dihedrally-up position. This method causes a more gradual turn, and is used in cases in which speed ahead is maintained.

Recently I was with a friend at Jharna Nullah, and within a few minutes we saw two cases in which a cheel dropped a piece of meat and caught it before it reached the ground. In each case the cheel was being chased by other birds. Apparently to drop a piece of food and again catch it in this way is a method used by cheels to baffle pursuit.

Cheels when swooping steeply downwards sometimes show to-and-fro rotations of large range round the longitudinal axis. For instance:—

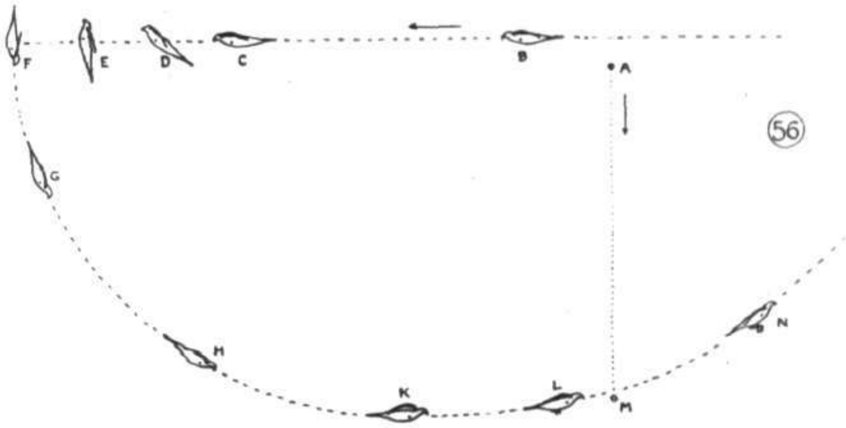


Fig. 56.—Movements of a cheel when catching food thrown to it in the air. A, a piece of bread falling while a cheel is gliding past at B. At C the cheel advances its wings. In consequence the bird rotates through 90° round its transverse axis, as shown at D and E. The cheel then rotated 180° round its dorso-ventral axis, as shown at F. The wings are now flexed and secondaries relaxed. The bird then swoops down, as shown at G and H, gradually extending its wings and increasing their camber. At K and L the wings are shown in the dihedrally-up position. This adjustment causes gradual rotation round the transverse axis. The bird consequently glides upwards, catching the bread, M, in its claws as it passes. The cheel carried out these manœuvres while the bread was falling from A to M, a distance of about 15 feet.

October 17th, 1910.—3.30.—When feeding my captive adjutant I threw some pieces of meat into the air. Some cheels swooping for these showed rapid to-and-fro oscillations round the longitudinal axis. Two of them after checking speed ahead by advancing wings showed rapid rotation round the dorso-ventral axis. During this rotation the wings were only slightly flexed.

According to my recollection of this incident, the adjutant was threatening the cheels by snapping its beak at them. In certain cases, therefore, the cheels had occasion to check speed suddenly

by advancing their wings. I recollect one of these cheels swooping towards a piece of meat, and oscillating round its longitudinal axis. As the meat had reached the ground and as the adjutant was walking up to it, the cheel changed its wing, rotated round its transverse axis to check speed, and glided away.

By the term "oscillation round the longitudinal axis," I mean that the bird became strongly canted over to one side, returned to a level keel, and then became canted in the other direction. There can be no doubt that this canting to one side or the other was not due to atmospheric irregularities. It must have been due to some more or less voluntary adjustment. The question arises—what was its nature?

In the above case, longitudinal-axis oscillation preceded the advancing of both wings. So far as I am aware similar longitudinal-axis oscillation only occurs if both wings are about to be advanced. For instance, cheels when playing together in the air often swoop downwards for short distances, and in so doing show the oscillation in question. Several times I have noticed such oscillations in the case of cheels swooping downwards in order to perch. In these cases the wings were placed dihedrally upwards to change the direction of the swoop. This was immediately followed by advancing to check speed. In each of these cases it seemed to me that the wing that became uppermost during the canting had been advanced. But this was merely an impression, not a definite observation.

On the other hand, so far as my experience goes, if the swoop is not going to be followed by advancing the wings no oscillation round the longitudinal axis occurs. For instance, if a cheel is swooping downwards to snatch a piece of food from the ground, it does not check its course by advancing the wings, but changes the direction of its swoop by placing the wings in a dihedrally-up position. When thus swooping downwards there is no appearance of lateral instability. Further, cheels and eagles sometimes swoop downwards and glide up again in one long curve without checking speed. This change of course is produced by varying the dihedral angle of the wings, and again no sign of lateral instability can be observed.

Thus it appears that longitudinal-axis oscillations only occur if the bird is about to advance both wings. That is to say, it is probable that the oscillation is due to some "anticipatory movement"; that is to say, to a movement anticipatory to advancing both wings. Obviously the movement cannot have been an advancing of both wings. It is doubtful whether increased flexing could have produced the effect observed, unless it was of such an extent as to be noticeable. The range of longitudinal-axis oscillation observed may have been as much as 60° or 80°. Further, flexing would not have been a movement of an anticipatory nature.

Let us consider whether advancing of the two wings alternately could have produced the effect observed.

I have already shown that advancing of both wings causes rotation upwards round the transverse axis. If both wings are advanced, their front edges and the head end of the bird are raised. At the same time the tail drops. Supposing only one wing is advanced, then the front edge of this wing will be raised. The front edge of the other wing is not raised. That is to say, the bird becomes canted.

Obviously, if canting can be produced by advancing one wing, canting in the same direction will also be produced by retiring the other wing. Possibly the following observation is an example of such an adjustment:—

November 16th, 1910.—At Jharna Nullah. 10.40.—A brown vulture flapping a few feet over my head showed a retirement of the inside wing. It was flying on a curved course.

I suggest that the movement observed was an adjustment for canting. Possibly the movement was accompanied by increased flexing, that is to say, by an adjustment for steering.

It is regrettable that so important a conclusion is based merely on inference and not on sufficient or certain observation. My suggestion is that a bird, if in gliding flight, when steering to one side, rotates one wing or wing tip, while at the same time the wing is retired, the rotation produces steering, and the retirement produces the requisite amount of canting. The implication is that lateral stability is, in part at least, maintained by advancing or retiring of one wing. This suggested method is obviously of great simplicity and one not involving any large decrease in wing efficiency.

It might be objected that the steering movements already described are in themselves sufficient to produce canting and that no further method is required. For instance, if in soarable air, a bird rotates a wing or wing tip, the angle of incidence is altered; the air ceases to drive the wing ahead. Its supporting power therefore diminishes. The bird, therefore, may become canted. Without pausing to discuss how far such an explanation can apply to unsoarable air, it can definitely be asserted that it will not meet the case of the cheel.

The cheel shows far greater agility when in the air than other birds with which I am acquainted. I was once watching a vulture in flap-gliding flight with a piece of meat in its claws. A cheel swooped down under the vulture, and as it passed snatched away the meat. From my knowledge of the habits of the cheel, I have little doubt that the cheel seized the meat in its claws. If so, the cheel must have suddenly rotated round its long axis through a very large angle. On other occasions I have seen a cheel gliding for a fraction of a second upside down. Twice I have seen a cheel gliding in the air catch another cheel by the claws. The two birds remained hanging on to each other by the claws for an appreciable time. The under bird was upside down. In each of these cases it was impossible to see how the cheel reached its unusual position, but there can be little doubt that sudden rotations round the longitudinal axis occurred.

In vultures, slight steering movements can occur without canting. In cheels large amounts of canting can occur without steering.

My suggestion as to the means employed for maintaining lateral stability is based on instances in which oscillations are produced by a presumed advancing of one wing. A further proof of the correctness of the suggestion would be obtained if a case could be brought forward in which longitudinal-axis oscillation was caused by a retirement of one wing. As a possible instance of such oscillation, the following observations may be quoted:—

August 21st, 1911.—On Tundla Road, near Jharna Nullah. At 6.30 p.m.—A large number of adjutants, during more than half-an-hour, were flap-gliding in the direction of the river (presumably to spend the night on a sandbank). They travelled at a height of less than 10 metres above the earth. The periods of flapping and gliding were each of only a few seconds' duration. No vertical flaps occurred before the glides. In all cases observed—probably more than 50 birds—an increase in the angle of incidence was seen to occur during each glide. The angle of incidence was at a minimum immediately after the flapping. It gradually, and, I think, continually, increased to reach its maximum just before the next period of flapping. This was easily seen. In three cases, in addition, a gradual increase in the dihedrally-up angle of the wings was seen to take place. In one case I saw slight oscillation round the longitudinal axis, apparently as a single to-and-fro movement, immediately after flapping. The range of movement of the wing tip was certainly less than 2 ins., and may have been about an inch. Previously, at Jharna Nullah, I had observed this oscillation in other species of birds. It is difficult to see. During the down stroke the adjutant makes a whistling, swishing sound, reminding one of the sound made by telegraph wires vibrating in a wind. This sound varies in amount. In two cases I was also able to hear a faint whistling sound during the gliding period. This resembled the sound one would expect to be made by air rushing into or out of a cavity. (I have frequently heard this "glide-whistle" since. It may possibly have to do with change of volume of the air sacs.)

In Chapter IX, I stated that it is probable that, in gliding, height is maintained at the expense of speed. I further suggested that this result is obtained by a gradual increase in the angle of incidence. It is satisfactory that, at length, I am able to bring forward the above observation, which amounts to direct evidence of the correctness of my suggestion.

But my purpose in noting the above observation is to discuss the probable meaning of the slight longitudinal-axis oscillation that immediately succeeded the flapping. I have seen this in other species of birds on two or three other occasions. As has already been shown, in flapping flight of the larger birds the wings are advanced. Therefore at the moment of the change from flapping to gliding, the wings have to be retired. If it chances that one wing is retired at a greater rate than the other, it is conceivable that a small lateral oscillation might be produced, supposing my view is correct as to the means employed for producing lateral stability. If this explanation were correct then one would expect this oscillation to be observed always, or at least frequently. But though I have often looked for it, I have only succeeded in seeing it on two or three occasions. Therefore it is necessary to entertain an alternative theory, namely, that the oscillation in question was due to some unusual atmospheric condition.

I am unable to decide between these two possibilities for the following curious reason. It is well known that, in reasoning, a preconceived idea has a very unwelcome influence in aiding one in coming too quickly to a conclusion. My experience is that, in observing, a preconceived idea has an unwelcome influence in the opposite direction, namely, that it may inhibit one's power of observation. At the beginning of this chapter I stated that if the consciousness is occupied by any feeling of surprise or interest, the power of making difficult observations is diminished. My experience is that, in addition, an expectation of what one is about to see may also inhibit the power of observing. This statement

applies to observation of minute movements lasting only a fraction of a second.

Originally I used frequently to enter in my notes that a particular observation was quite unexpected. I know now that this is more or less the rule. I may make a difficult observation on two or three days running. Then, as soon as I have understood that the observation has some theoretical interest, and make an attempt to repeat my observation, I find that I am incapable of seeing the movement. My power of recognising the movement only returns after the lapse of several months. Hence in the case of the oscillation under discussion, it being a movement very difficult to see, my failure to see it may be due to the psychical inhibition above described. Hence I am unable to decide between the two suggested theories, and further have a sort of uneasy consciousness that an ampler knowledge of the subject might lead to yet a third view of the nature of the movement.

The common dove frequently flaps nearly vertically upwards to a height of 5 to 10 metres above the tree tops. Then it glides downwards in long sweeping curves with wings dihedrally down and tail expanded. Twice I have seen this dove advance the inside wing during or after a turn, as if with the object of preventing canting. This dove habitually turns (in the horizontal plane) in a curve of long radius with scarcely any canting.

I doubt whether the means employed for producing canting will ever be discovered by direct observation in the case of such expert flyers as the vulture and the cheel. It is possible that the adjustment may be seen in the case of some bird of clumsy flight.

(To be continued.)

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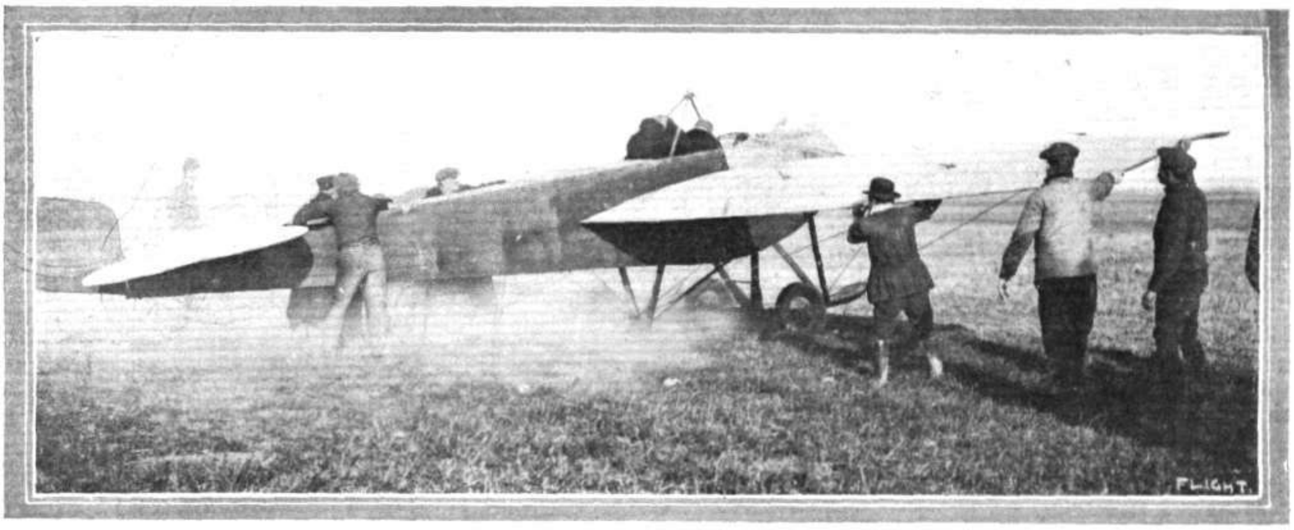
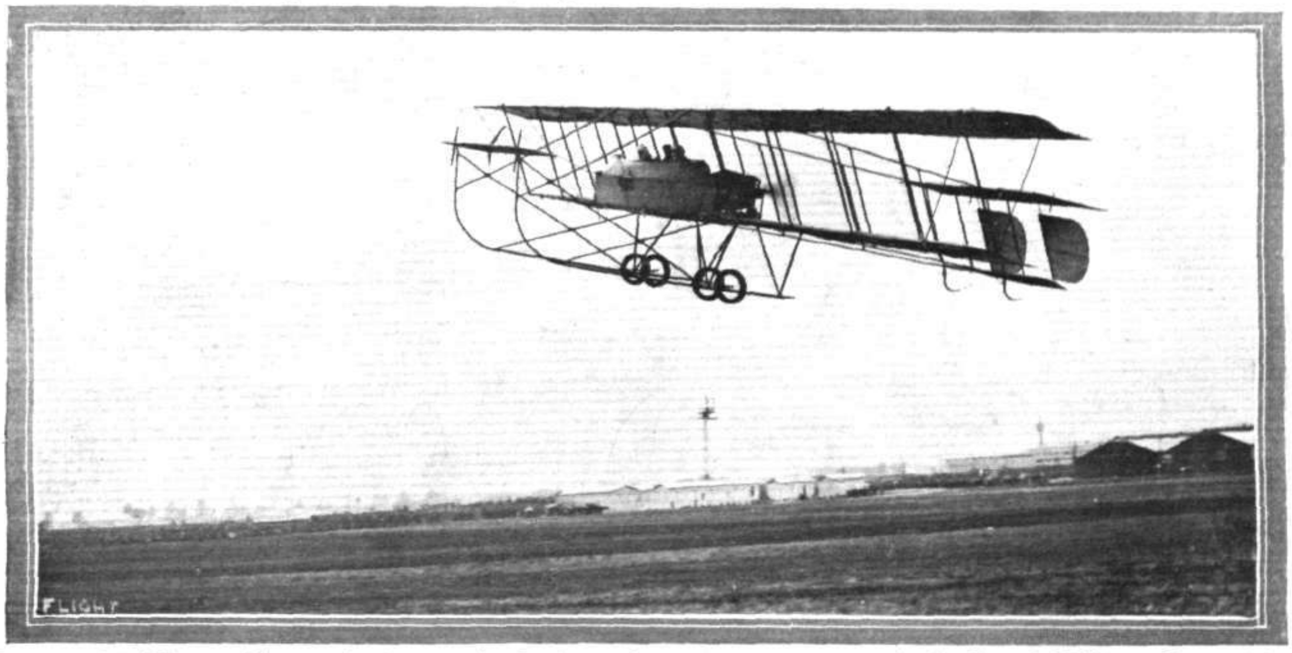
THE MILITARY ASPECT OF AVIATION.

SOME instructive comments on the use of aeroplanes from a military point of view were offered by Capt. C. J. Burke in a lecture at the Royal United Service Institution on the 15th inst. One the use of aeroplanes and airships in manœuvres was, as was reconnaisance. To-day an average type of machine could be depended upon to make a successful flight of 180 miles on 80 per cent. of the days of the year. Not only so, but the early hours of the morning and those just preceding nightfall were the most



Mr. Weymann just before the signal to start from Rheims on his Nieuport monoplane for the final cross-country speed test in the Military Aviation Contest, in which he has been adjudged the premier position, he having covered the 300 kiloms. in the net time of 2 hrs. 34 mins.

he pointed out, that the ordinary topographical features, which at one time used to play a great part in the conduct of war, had now largely lost their significance. Forests, hills and streams no longer constituted insuperable obstacles or impenetrable screens for the concealment of troops. The principal work of the military aeroplane suitable times for flying, and also the most decisive periods of the day from a military point of view. A commander could then rely on despatching a staff officer on an aeroplane to a point 60 miles away and receiving reliable information within three hours.



Barra on his Maurice Farman biplane in the final speed test in connection with the French Military Competition.

A Study of Bird Flight

By Dr. E. H. Hankin. M.A. DSc.

CHAPTER XXXVI.—Heat Eddies and Soarability.

IN previous chapters it has been shown that solar energy is the source of the energy of ordinary soarability. We have now to consider the question whether soarability is due to ascending currents of air caused by the heat of the sun.

On a hot day distant objects may appear to be in tremulous shimmering movement owing to the rising of masses of heated air. This effect is well known on rifle ranges in India, where it is referred to as "mirage," and is known to interfere with shooting as soon as the sun gets warm. It is also known that this shimmering appearance is more easily seen through a binocular than with the naked eye.

In investigating these "heat eddies," I found that it is preferable for the binocular to be held firmly on a stand by means of a clamp. It is advisable to direct the binocular to some horizontal white line on a building at some distance away. The object looked at should occupy the centre of the field of view. While looking at the object the head must be held steady. The slightest movement of the head or of the instrument greatly adds to the difficulty of seeing heat eddies, especially at the time of their commencement in the early morning.

In order to find out whether one phenomenon is the cause of another, it is necessary to be able to measure both of the phenomena. Then it is possible to see whether a variation of one is followed by a variation of the other. Therefore, in order to determine whether heat eddies are the cause of soarability, it is necessary to have some means of measuring these two phenomena.

The only measure of soarability available is the behaviour of cheels. In my later observations I found it advisable to observe cheels over the city rather than over the cantonment. Usually, but not always, cheels begin circling over the houses of the city a few minutes before they start over the trees and gardens of the cantonment.

A method of measuring heat eddies to some extent was furnished by the fact that they always develop in a certain order on different buildings in and near the Agra Fort when viewed from the roof of my house.

Supposing the weather is perfectly fine and undisturbed, and supposing the conditions are fully suitable for observation, the following is the sequence of events :—

1. Firstly, heat eddies appear on the edge of the roof of a small shed situated on a level with the base of the fort walls (as seen from my house). The shed is situated a few hundred yards from the fort.

2. From two minutes to a quarter of an hour after the appearance of the shed eddies, heat eddies may be seen to commence on the top of the wall of a small cemetery that is situated near the shed. The cemetery is on slightly higher ground than the shed, but the top of its wall is on a slightly lower level than the edge of the roof of the shed.

3. The next building to show eddies is the outer lower wall of the fort (near the Umar Singh Gate). These eddies are usually difficult to see, and I have not often entered the time of their appearance in my notes. There is usually an interval of several minutes between the cemetery eddies and the lower battlement eddies.

4. A few minutes later the wall of the bastion near the Umar Singh Gate appears distorted. The appearance is as if one was looking at a picture painted on canvas, and as if some one was pushing the canvas to and fro.

5. The level of the distortion of the bastion slowly rises, and a few minutes later eddies appear on the top of the bastion.

About the time that eddies appear on the lower wall or battlements, eddies also commence on a barrack building in the fort. This building is in a straight line beyond the top of the Umar Singh Gate bastion. Eddies only appear on the bastion when they have reached a certain intensity on the barrack.

As a rule, at the moment that heat eddies appear on this particular bastion in the fort, the air becomes soarable. Supposing there is no wind, then, as a rule, not a single cheel will have been visible before the appearance of the bastion eddies. Within a minute of these eddies developing eight or ten cheels may be seen circling over different parts of the city. In rare cases there may be a delay of five minutes between the development of bastion eddies and the development of soarability. On four or five occasions, while watching cheels circling at the beginning of soarability, I noticed that their flight changed from circling to flap-circling. On each of these occasions, on turning my binocular from the city back to the bastion in the fort (a mile or two away), I found that its eddies had ceased. When a few minutes later its eddies recommenced, soarability again commenced in the air over the city.

In the presence of wind occasionally local or temporary soarability may be observed before the appearance of heat eddies on the bastion.

Thus in perfectly fine weather, and in nearly every month of the year, it is possible for me, by means of my binocular, to find out whether or not the air is soarable, and if the air is not soarable to make a guess as to how soon the change to soarability will occur.

The following are examples of my observations :—

April 19th, 1910.—7.52.—Heat eddies visible on shed.

8.19.—Head eddies visible on cemetery.

8.40.—No cheels up.

8.42.—Heat eddies on lower battlements.

8.43.—Heat eddies visible on bastion.

8 45.—Cheels circling in city and near. Dihedrally-up position of wings noticed.

8.46.—One cheel up near Agra Club. Eighteen circling in city.

A year later a similar succession of phenomena was observed. For instance :—

April 11th, 1911.—7.50.—Wind occasionally perceptible from west, but leaves generally still. Smoke rising and spreading out in layers. Dust haze. Eddies on shed and cemetery.

7.55.—Heat eddies slight on barrack.

8.0.—Eddies more on barrack.

8.15.—Wind coming from S.W. as shown by smoke.

8.19.—Slight eddies on bastion.

8.20.—One cheel circled and glided down up wind.

8.21.—Slight eddies on bastion.

8.22.—Four cheels circling at low level in city and two over fort.

8.24.—Nine cheels circling at low level in city and two at high level over fort. Eddies stronger on bastion.

8.26 —Seven cheels circling at low level and three at high level over city.

The following table shows the times of commencement of heat eddies and soarability, together with certain meteorological data* in different months of the year :—

Date.	Pressure.	Wind.	Temperature at 8 a.m.	Humidity at 8 a.m.	Eddies. Shed.	Eddies. Cemetery.	Eddies. Bastion.	Soarability.
1910.								
Mar. 22	29·867	Calm	69·2	34	—	8.5	8.28	8.28
,, 24	29·797	,,	74·2	32	8.17	8.24	8.41	8.44
April 10	29·712	W.N.W.	80·7	15	—	8.7	8.10	8.14
,, 18	29·604	S.	87·7	23	7.47	8.0	8.9	8.14
May 17	29·647	N.N.W.	89·7	23	7.22	7.34	7.52	7.58G.
,, 27	29·566	E.S.E.	92·2	45	7.4	7.7	7.9 and 7.13	7.9 and 7.14
June 1	29·551	W.	89·2	58	7.23	7.25	7.28	7.29
Aug. 7	29·419	E.S.E.	85·2	81	7.57	7.58	7.59	8.0
,, 22	29·703	,,	87·7	71	6.50	6.53	6.55	6.58
Sept. 4	29·500	W.	85·2	72	7.47	7.48	7.53	7.50
,, 26	29·738	E.	87·2	76	7.15	7.15	7.25	7.38
Oct. 11	29·856	S.E.	77·7	59	8.20	8.30	1.45	8.46
,, 27	30·001	W.	71·7	56	8.37	8.42	9.18	9.20
Nov. 13	29·976	W.N.W.	66·2	57	—	—	9.34	8.37
,, 25	30·018	W.	58·2	45	at 8.50	—	9.3 and 9.7	9.5 and 9.11
Dec. 10	29·986	,,	56·7	72	8.57	9.10	d 9.45	9.43
,, 30	30·109	E.S.E.	52·7	70	9.17	9.29	9.44	9.35
1911.								
Jan. 11	30·037	W.N.W.	59·2	82	at 9.20	—	9.23	9.24
,, 24	29·870	E.	59·2	85	at 8.55	—	9.0	9.1
Feb. 8	30·026	S.E.	53·2	58	at 8.45	—	8.56	8.56
,, 10	30·103	,,	50·2	49	8.37	8.40	8.56	8.56
April 7	29·773	E.S.E.	78·7	28	at 8.40	—	8.10	8.7
,, 11	29·691	S.S.E.	82·2	31	at 7.50	—	8.19	8.22

* These data, except in certain cases the wind direction, are taken from official records.

The foregoing table contains a selection taken at random from a large number of observations. It serves to show that various meteorological factors, such as pressure, temperature, &c., have no influence on soarability, while the development of soarability is closely connected with the development of heat eddies. In two cases in the above table (May 27th, 1910, and November 25th, 1910) two figures are given for commencement of bastion eddies and soarability. In each of these cases eddies commenced on the bastion, and cheels began soaring at the earlier of the two times. Then, in each case, the cheels began flap-circling or settled, and the bastion eddies ceased. After an interval, eddies and soarability re-commenced as indicated by the second entry. The letter G against the entries for May 17th, 1910, is intended to indicate that the development of soarability was gradual. It occasionally happens that soarability may be developed for a short time over a small area some minutes before its general development. This is especially the case during the monsoon season. In the case of December 10th and 30th, 1910, no true eddies, but only an appearance of distortion, could be seen on the bastion at the times stated.

The facts above described amount to a strong proof that, on the dates mentioned, there was some connection between the development of heat eddies and the development of soarability. It remains to be discussed whether this connection is casual or merely incidental.

Before entering on this discussion it will be advisable to look back at the facts already established relating to the nature of soarability. Even the earliest observations described proved definitely that soarability is not due to the bird taking advantage of irregular and chance currents of ascending air. The existence of different modes of soaring flight, the proofs that these different modes of flight require different amounts of air energy, the regularity of circling and other facts, prove that if soarability is due to ascending currents, these currents must be of small size and must be uniformly distributed in soarable air.

Existing evidence appears to show that heat eddies are of small size, and that they are uniformly distributed. Consequently, from this point of view, it is a priori possible that they are the cause of soarability.

Supposing, in the following chapters, I succeed in proving that soarability is not caused by heat eddies, then it appears to me that the idea that soarability has to do with ascending currents (in the ordinary sense of the word) must be regarded as negatived in the present state of knowledge. If one set of air currents, small in size and uniformly distributed, are not the cause of soarability, it becomes a very rash assumption that there is another set of ascending currents, also of small size and also uniformly distributed, that are the cause of soarability.

CHAPTER XXXVII.—Heat Eddies not the cause of Soarability.

It is safe to assume that the heat eddies described in the preceding chapter are caused by the heat of the sun. They may, therefore, be more particularly described as "sun eddies." Two other kinds of heat eddies are known to me, which are not directly caused by the heat of the sun, and which have no relation to soarability. These I propose now to describe.

Though I have made no systematic observations on the point, I have, on several occasions, noticed that there is a decrease in the intensity of sun eddies during the afternoon as soarability decreases. But towards sunset there is a fall in the temperature of the air. It therefore becomes cold relatively to the earth. Hence (in hot weather) buildings which have accumulated sun heat during the day begin, at this time, to warm the air in contact with them. Heat eddies are therefore produced. These heat eddies may be called "earth eddies." They often are stronger than the sun eddies observed at the commencement of soarability. They develop and acquire intensity at a time when soarability near the earth is decreasing. For instance :—

23rd March, 1910.—4.45.—Air at low level still soarable.

5.0.—Eddies slight on cemetery and bastion. None on Taj. Slight on Taj Mosque and Taj Garden Kiosque.

5.9.—Air at low level unsoarable. No heat eddies on bastion shed or cemetery.

5 50.—Strong earth eddies on Taj Mosque, Taj, Taj Garden Kiosque, and on Jawab (a building which was then in shadow of the Taj dome).

When the weather is hot these earth eddies appear to persist all night, since in the early morning they may be seen over all the larger buildings as soon as there is enough light for them to be visible. As the sun gathers strength they die away. Some time later sun eddies begin, and are followed, as previously described, by the development of soarability. I have seen these earth eddies in the early morning, over all the buildings of the fort, as strongly marked as are sun eddies an hour after soarability has been established. Nevertheless, there was no sign of soarability. A few cheels occasionally in the air in the fort were all in flapping flight.

Another kind of heat eddies may be described as "air eddies," as they are produced by a current of cold air striking the heated surface of the earth. If a dust-storm is followed by rain, it may produce a fall of temperature. Dust storms, in which the wind feels cold, may produce "air eddies." This may happen in cases in which the air is probably not soarable. For instance :—

April 21st, 1910.—9.30 to 10 p.m.—A dust-storm came up from the west. Lightning in the distance. Air eddies were seen on the upper and windward side of the moon, which was nearly full. The eddies were only visible as the dust was clearing off, and then were not continuous. Later, when the storm had cleared off, but wind was still blowing, no eddies were visible on the moon.

I have seen air eddies over the fort buildings in front of an advancing rain-storm, which continued when the buildings were under heavy rain, and were visible for three or four minutes under these conditions. On one occasion (July 29th, 1910) I noticed that these air eddies (formed near rain-showers) seemed to differ from sun eddies, in that they were visible on vertical as much as on horizontal lines of buildings. Also they seemed more fine-grained. The air was unsoarable.

Sun eddies and earth eddies, though different in origin, are when formed one and the same. They merely differ because I have given them different names. The presence of earth eddies does not cause soarability. Therefore the presence of sun eddies, *per se*, does not cause soarability. So far as the evidence, at present brought forward, goes, it might be thought that sun eddies differ in some unknown way from earth eddies, and that this unknown difference enables the sun eddies to produce soarability.

But I have now to bring forward evidence to show that in the presence of thin cloud, soarability may develop at the normal time in the morning in the complete absence of any trace of heat eddies. The evidence suggests even that the energy that produces soarability can penetrate thin cloud more easily than the energy that produces heat eddies. The following are examples of this occurrence, which, it may be noted, have been recorded at different seasons of the year :—

Date.		Pressure.	Wind.	Temperature, 8 a.m.	Humidity.	Soarability began at	Remarks.
1910.							
June	2	29·588	S.	90·2	50	7.51	Patches of cloud, slight eddies on shed
July	22	29·621	W.N.W.	91·2	56	7.40	Glare, no eddies; soarability developed gradually
Aug.	9	29·457	N.E.	87·2	74	6.55	Thin cloud, no eddies
,,	12	29·411	W.S.W.	81·2	87	8.6	Glare, no eddies
,,	13	29·458	S.S.E.	81·2	81	7.55	,,
,,	26	29·659	E.	81·7	89	7.20	,,
,,	27	29·659	W.	81·2	91	8.20	,,
Sept.	7	29·434	W.N.W.	79·2	91	8.0	,, Similar results on three following days
Nov.	9	29·944	E.S.E.	69·2	70	9.4	Glare, no eddies
Dec.	23	30·080	W.N.W.	47·7	49	10.5	Cloud, no eddies
1911.							
Jan.	8	30·157	Calm	54·7	90	9.33	,,
,,	9	30·143	,,	59·7	85	9.30	,,
April	9	29·736	W.N.W.	80·2	37	7.55	No cloud, but sunshine dim from dust in air at high level. Eddies on shed and cemetery, none on bastion

In many of the above instances an increase of glare was apparent at the time when soarability developed. In these cases in which the sky is obscured by thin cloud and a strong glare of light is present, there is no noticeable delay in the time of development of soarability. In other cases in which the sun is obscured by heavy cloud, the development of soarability may be delayed until the sun comes out. If the sun comes out suddenly then soarability develops suddenly. If, on the other hand, the clouds dissolve gradually, then soarability will develop gradually.

It might be objected that in the above instances heat eddies developed but were not visible owing to bad light. But cases are known to me in which eddies are visible under cloud shadow. For instance, in the following striking case, eddies, in the early morning, were visible under cloud shadow without soarability. The eddies gradually diminished and vanished, and after they had gone the air became soarable to a slight degree :—

September 21st, 1910.—At 6.45.—Cloud in two layers. The lower layer moving slowly from north. Wind cold, puffy, moving small branches. No sunshine or glare. Strong eddies on

Students' Hostel, Sekundra, cemetery, shed, bastion, barracks and city houses. No cheels up.

7.0.—Eddies as before. No glare. No cheels up, except cheels in ascending current over Delhi Gate of Fort. These were gliding at low level.

7.15.—Eddies on hostel slight. Sekundra, no eddies, but it appeared as if out of focus. Strong eddies on city houses, slight on bastion. Strong on barracks. Slight on cemetery. Shed appeared as if in bad focus.

7.20.—No sun. No glare.

7.30.—No cheels up. Slight eddies on hostel, city houses, barracks. None on Sekundra, bastion, shed, or cemetery. Glare.

7.45.—Eddies on hostel, and slight on barracks. None on city houses, Sekundra, shed, cemetery, or bastion. No cheels up.

8.5.—No eddies anywhere.

8.7.—Five cheels circling at low level in far part of the city; they appear to be in strong glare or sunshine.

8.16.—Five cheels circling and two skimming over buildings.

8.20.—No cheels up. No eddies. Glare.

8.25.—Eight cheels flap-circling.

9.30.—Cheels lee-looping.

10.0.—Thin cirrus over sun. No eddies, except on hostel. Cheels and scavengers circling both at low and high levels. No flex-gliding. Cheels flapping for going up wind.

10.3.—Two cheels seen flex-gliding, and one scavenger flex-gliding with loss of height and then flap-gliding.

During the monsoon season (as seen both in 1910 and 1911) it is exceptional for there to be any relation between bastion eddies and soarability. But, as will be described in a later chapter, on many occasions during the monsoon season, when no eddies were visible, there is reason for believing that sun energy was the source of the soarability observed.

Thus all attempts to prove that sun soarability is due to moving masses of air have so far failed. So far as the evidence goes, it appears that when air is fully soarable, every minute portion of it is as ready to furnish energy for soaring flight as any other portion. If soaring birds get energy from the air by meeting eddies (of unknown nature), and extinguishing their motion, then these eddies must not only be uniformly distributed, but also must be of very minute size. Another suggestion is possible, namely, that soarable air contains unstable modification or compound that decomposes with explosive violence when in contact with the underside of a vulture's wing. This is not a view to be lightly dismissed or lightly accepted. On the other hand the view that it is legitimate to assume the existence of an unknown ascending current to explain every movement of the soaring bird is a view that has led to no new discoveries, and that has discouraged research in a direction that promises to be of interest from several different aspects.

(To be continued.)

AN ARMY AIR BATTALION RESERVE.

A SPECIAL Army Order issued on the 24th ult. states that with a view to forming a reserve for the expansion of the Army Air Battalion on mobilization, a number of officers of the Regular Army will be selected as suitable for Army aviation work.

An officer desirous of being selected must have not less than two years' service, be medically fit, and be recommended by his commanding officer. If he is not in possession of a pilot's certificate he must obtain one at his own expense. Preference will be given to unmarried officers, and married officers will only be considered in exceptional cases.

An officer selected for Army aviation work will be paid under instructions from the War Office a reward of £75 if he is in possession of a pilot's certificate, or after he has obtained one.

An officer so selected will be required to undergo a further test to be arranged by the Commandant, Air Battalion, after a short course in the Army Air School, in order to qualify for a certificate as Army aviator.

Applications for selection will be transmitted through General Officers Commanding-in-Chief to the War Office.

AIR SCOUTING COURSE ON T.S. "MERCURY."

ON Monday last the special course of instruction in aeronautics which Mr. C. B. Fry, Hon. Director of the T.S. "Mercury," has arranged for his boys was inaugurated. This course forms part of the scheme lately evolved by the Young Aerial League (227, Strand, London, W.C.) to give boy scouts a simplified aeronautical training which would enable them to identify machines, estimate their height, speed, direction of flight, &c., thus enabling them to be of immediate service to their country in case of invasion. The knowledge the scouts will acquire will also help them to qualify rapidly and surely for their airman's badge.

The "Mercury" boys are very keen to study the new science, and are fully aware of the value which a sound aeronautical training will be to future sailors.

Mr. Blin Desbleds, lecturer in aeronautical engineering at the Polytechnic, London, who gave the inaugural address, dealt especially with the different ways in which the new means of locomotion is likely to affect the Navy. He concluded his address by saying that the time was fast approaching when a new field of activity would be opened for sailors with aeronautical knowledge. The "Mercury" boys should consider themselves very fortunate to be the first to have an opportunity of acquiring some aeronautical knowledge in addition to their usual naval training, for they would be more valuable to the Navy than ordinary sailors, and would consequently be entitled to greater considerations.

MR. FRANK McCLEAN AND HIS SHORT TANDEM TWIN-ENGINED MACHINE.—On the left just starting away from the Eastchurch grounds, with Lieut. Samson as passenger, and on the right Mr. McClean helping to store his machine after his first flight on it.

A Study of Bird Flight

By Dr. E. H. Hankin, M.A. DSc.
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CHAPTER XXXVIII.—**The Position of the Centre of Gravity under different Conditions of Flight.**

THE outer third of the wing of a vulture consists of the wing tips. The inner two-thirds of the wing are cambered (when the wing is extended), and are concerned with lifting effort in unsoarable air and with lifting and tractive effort in soarable air. The centre of lifting and tractive effort of each wing may therefore be taken as being near the junction of its inner and middle thirds. The wing sections shown in the following figures may be regarded as taken at this point.

The following diagram (Fig. 57) represents a side view of a vulture when gliding in a straight line in soarable air.

It will be seen that the position of the centre of effort of the wings is vertically above the centre of gravity. Supposing the vulture advances its wings, thus (Fig. 58), then a couple is produced tending to rotate the bird upwards round its transverse axis. Such rotation, as we have seen, actually occurs. The bird rotates until it assumes the following position (Fig. 59).

Thus the centre of lifting effort re-acquires its position vertically above the centre of gravity. Conversely if the bird retires its wings, a couple originates that rotates the bird in the opposite direction, thus (Fig. 60), and again the centre of effort is vertically above the centre of gravity (Fig. 61).

Therefore, so long as the bird is gliding in a straight line in unsoarable air, the centre of effort of the wings is vertically above the centre of gravity. If the centre of effort is displaced, rotation round the transverse axis at once occurs until the centre of effort is again vertically above the centre of gravity. We have already seen that when a bird is gliding in an ascending current the same law holds. Under these conditions the centre of effort is near the centre of area of the wing, and in order to retain gliding horizontally the bird advances its wings until the lift is again vertically above the weight.

Does the same relation hold when the bird is subjected to a propelling force, as in flapping flight or when soaring?

Let us first consider the case of flapping flight. We have already seen that if the bird while flapping changes its wings from the "straight" to the "retired" position, it rotates round its transverse axis, and the direction of its flight is in a downward direction. Conversely, if, as in stop flapping, the bird advances its wings it rotates upwards round the transverse axis. These facts suggest that the law holds good. But if this is the case, why is it that the wings are advanced in slow horizontal flight, and why does the amount of advancing diminish as speed increases?

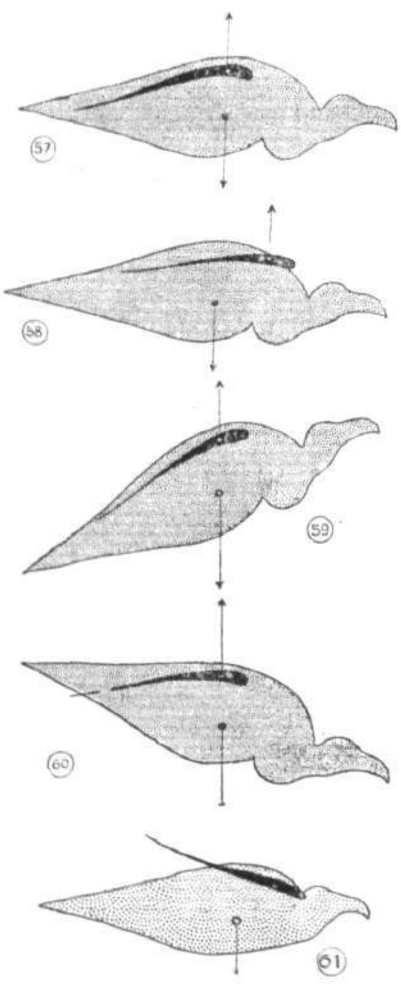


Fig. 57.—Section of a vulture gliding in unsoarable air.
Fig. 58.—Effect of advancing wings, first position.
Fig. 59.—Effect of advancing wings, second position.
Fig. 60.—Effect of retiring wings.
Fig. 61.—Section of vulture in flapping flight.

Supposing a bird is gliding horizontally in calm air, and someone momentarily catches hold of its tail, so as to check speed ahead. Supposing, in consequence, the bird was to flap its wings up and down in order to regain speed ahead. Then, at first, as the air strikes the surface of the wing nearly at a right angle, the "lift" is at a point near the centre of area. Hence the bird has to advance its wings in order to bring the "lift" over the "weight." Hence the wings can be seen to be advanced in slow flapping flight. But as speed ahead increases, the angle of incidence diminishes. Consequently the "lift" approaches the

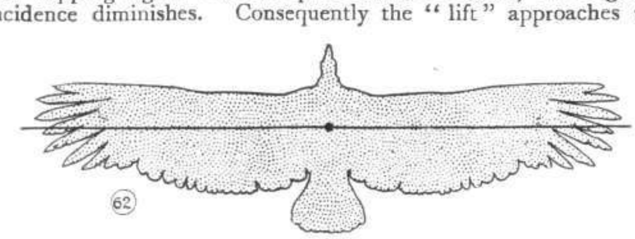


Fig. 62.—Outline of a vulture circling in air not fully soarable, or circling in fully soarable air without effort to gain height.

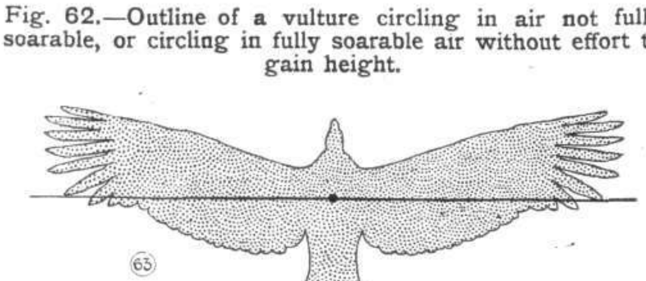


Fig. 63.—Outline of a vulture circling in fully soarable air and with effort to gain height.

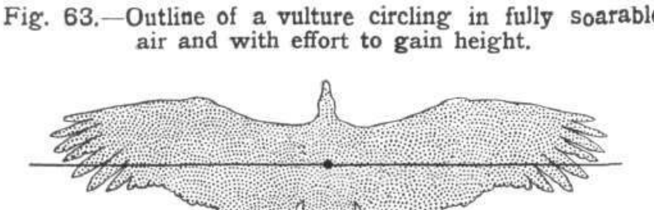


Fig. 64.—Outline of a vulture slow flex-gliding (8 metres per second).

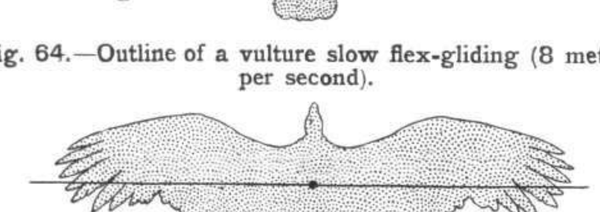


Fig. 65.—Outline of a vulture flex-gliding at medium speed (12 metres per second).

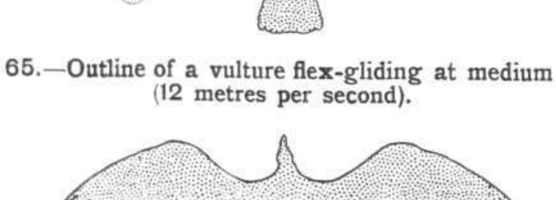


Fig. 66.—Outline of a vulture fast flex-gliding (22 metres per second).

anterior margin of the wing. Therefore the wing has to be retired, in order to keep the "lift" vertically over the "weight." Hence in fast horizontal flapping flight no advancing of the wings is to be observed.

This description is only approximately correct. The force of flapping has to neutralise not only the weight but also the resistance to forward movement through the air. If a bird is in movement in the air it may be regarded as being acted on by four chief forces, namely, "lift," "weight," "pull" and "drag." In flapping flight the force exerted by the wings may be regarded as compounded of "lift" and "pull." Of these two forces the "lift" acts vertically, and the "pull" horizontally. Their resultant may be called the "total pull." It is a force acting upwards and forwards. It balances a force compounded of the "weight" and the "drag." This force, which acts downwards and backwards, may be called the "total drag."

If a bird is taking energy from the air in soaring flight it is being subjected to a propelling force. Therefore, the forces acting on it may be regarded as resulting in a "total pull" and a "total drag." By examining the position of the wings in different kinds of soaring flight we may be able to arrive at some conclusion as to the direction from which the unknown force of soarability acts.

Figs. 62 to 66 show outlines of a vulture when circling and when flex-gliding at different speeds. It will be seen that as the speed of flex-gliding increases the larger is the proportion of wing area in front of the level of the centre of gravity.

If a vulture is circling in fully soarable air with effort to gain height, its wings, besides being advanced, are placed in a dihedrally-up position, as shown in the following diagram (Fig. 67).

A further reference to this employment of the dihedrally-up position will be made when I come to discuss the functions of the wing tips.

A section of a vulture when slow flex-gliding may be represented thus (Fig. 68).

As already stated, this position is apparently identical with that assumed for gliding with speed ahead in an ascending current. In this latter case the angle of incidence is about 90°. In other words, the "total pull" acts in a direction at right angles to the surface of the wing, or nearly so. Therefore, in slow flex-gliding, the unknown force of soarability must also act in a direction approximately at right angles to the surface of the wing.

If a vulture, when slow flex-gliding, wishes to increase its speed, it slightly increases the flexure of its wings. The secondary quills are thereby relaxed, and assume the following position (Fig. 69).

Thus the wings of a fast flex-gliding vulture are disposed in a way which, if imitated by a power-driven aeroplane, would rapidly bring the machine to the earth. That the wings actually assume the position shown is a matter of comparatively easy observation. It is important to realise that the position of the surface of the wing is due to air-pressure, or more particularly by a pressure exerted by soarable air when under the vulture's wing. Flexing the wing, at the carpal-joint, results in relaxing the ligaments that hold the secondary quills in position. This relaxing of the ligaments, of itself, has no power of putting the secondary quills in their new position. It merely allows the feathers to take the position given to them by the pressure of the air. A little consideration will show that in fast flex-gliding the pressure is exerted at right angles to the surface of the wing, as is the case in slow flex-gliding. In Fig. 70, the disposition of the wing in slow flex-gliding is shown at A. The arrows represent the position and direction of the "total pull" and "total drag."

The position of affairs in fast flex-gliding is shown at C. The weight is as before. The resistance to passage through the air is increased owing to the increased speed. Therefore the "total drag" must act in a more backward direction. Hence I have drawn the "total drag" arrow in C pointing more backwards and less downwards than in A. But the "total drag" must act in a line with the "total pull." In fast flex-gliding the wing is further advanced, as I have drawn it at C. Hence, as shown at C, the force is still exerted at right angles to the surface and at the centre of area, or thereabouts. If the bird was to increase speed merely by relaxing the secondaries, as shown at B, a couple would originate tending to cause rotation downwards round the transverse axis. Hence in flex-gliding the faster the speed the more the wings are advanced.

Therefore there seems to be no probable alternative to the conclusion that soarable air exerts a pressure on the under side of the wing of the flex-gliding vulture. It has already been shown that there are no observational or experimental reasons for assuming the presence of ascending currents in the neighbourhood of the bird that could be invoked as an explanation of this pressure. The view that ascending currents, in the ordinary sense of the word, have to do with soarability fails completely to explain why pressure is still exerted at right angles to the surface of the wings when the latter are fully advanced and relaxed as in fast flex-gliding.

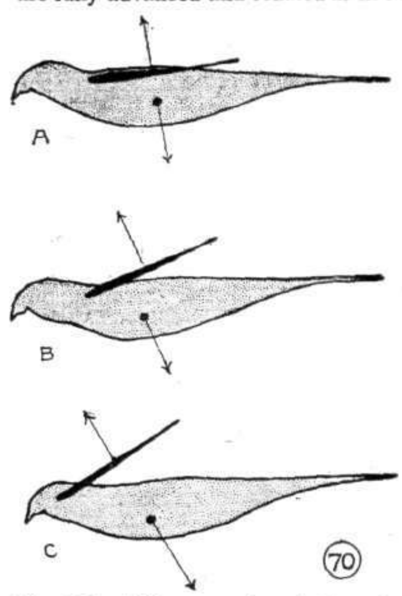


Fig. 70.—Diagram showing position of "pull" and "drag," at A in slow flex-gliding, and at C in fast flex-gliding.

"At B is shown an imaginary case in which the wings are placed in the fast flex-gliding position, except that they are not advanced. Hence between the 'pull' and the 'drag' there is a couple tending to rotate the bird round its transverse axis."

That is to say, the facts of the case in slow flex-gliding do not necessarily exclude ascending currents. But the facts of the case in fast flex-gliding furnish evidence that ascending currents are not the cause of soarability. Let us consider the case from another point of view.

Adjutant birds have an extensible pouch that hangs down from the lower part of the neck. Towards the end of the monsoon season before they leave Agra for their breeding haunts, this pouch is often extended and may reach a length of sixteen or more inches. Sometimes the pouch is seen extended while the bird is in soaring flight. It can then be seen swaying slowly to and fro in the air. Owing to its weight, and owing to the air pressure from the forward movement of the bird, the pouch, in general, hangs downwards and backwards. It shows no indication of being pressed forwards and upwards. But the air under the wing of the bird, within a few inches of the swaying pouch, is pressing the quill feathers upwards and forwards with a force that not only sustains the bird but that also propels it at a speed of thirty or forty miles an hour. How could ascending currents exert this tremendous force on the wings of the bird, and yet have as little apparent action on the pouch as they have on a floating feather in its neighbourhood?

There can be no doubt that the pressure on the under side of the adjutant's wing is exerted by air in motion. The motion is in such a direction as to exert pressure at right angles to the surface. An explosion of a gas is exerted at right angles to a flat surface. Therefore air as it passes under the wing of a soaring bird must undergo some change by which energy is liberated and which in the direction of the resulting force resembles the explosion of a gas.

In one of the earlier chapters I pointed out that it was inconceivable that the bird could get energy out of air if air is homogeneous, unless the passage of the vulture's wing causes some change or decomposition. Obviously, as shown, air from the point of view of soarability, is, in general, homogeneous. Therefore the conclusion is inevitable that the passage of the wing causes some change or decomposition in the air. If there is decomposition or explosion there must be something in soarable air that can decompose or explode. I propose to return to the question of this unknown something in a later chapter. (*To be continued.*)

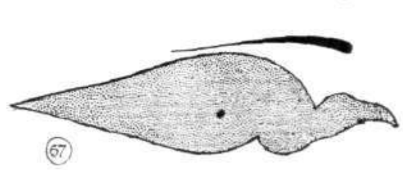


Fig. 67.—Section of a vulture circling.

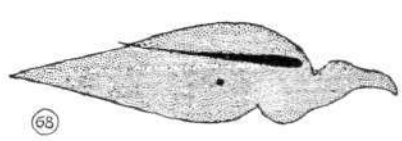


Fig. 68.—Section of a vulture slow flex-gliding.

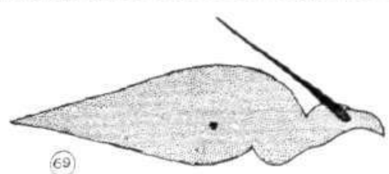


Fig. 69.—Section of a vulture fast flex-gliding.

A Study of Bird Flight

By Dr. E. H. Hankin. M.A. DSc.

CHAPTER XXXIX.—"Ergaer," the Physical Basis of Soarability.

It will be of interest to review briefly the facts that have been described in order to see what general conclusion can now be drawn as to the nature of soarability.

The first and chief question is what is the source of the energy involved? In answer to this question, there are, in the first place, two distinct possibilities to be considered. Either the energy is furnished by the bird, or, on the other hand, it is furnished by the air. The idea that the energy of soaring is due to the bird, that is to say, that it is derived from minute and undiscovered movements of the wings is, I think, excluded by the following facts. Firstly, soaring flight usually commences at a definite time of day, differing for each species of bird. It is impossible to imagine why a bird should be able to make minute movements, as suggested, after a definite time and not before it. Secondly, the idea is excluded by the complicated relation of cloud shadow to soarability. Thirdly, the idea does not harmonise with the discovery of different kinds of soaring flight in which the wings have different dispositions, and in which, as has been proved, different amounts of energy are involved.

Therefore, we are obliged to accept the alternative, namely, the view that the soaring bird gets its energy from the air. Here again we are confronted by two possibilities. Before the bird makes use of this energy, this energy must be in the air. It may be present either as the kinetic energy of moving masses of air, or, on the other hand, it may be present in the form of potential energy, that is to say, stored up in some structure, which structure, by decomposing, liberates the energy required for soaring flight. Let us consider these possibilities in order.

The suggestion that we are dealing with the energy of moving masses of air must be split up into two possibilities, which we may consider separately.

Firstly, it is conceivable that the soaring bird takes advantage of ascending currents reflected upwards from the walls of high buildings, &c. This suggestion becomes improbable in view of the extraordinary regularity of soaring flight as was exemplified in Chapter XI in a description of the circling of cranes. Secondly, the statement often dogmatically made that soaring birds show skill in finding and taking advantage of ascending currents is absolutely opposed to the facts in the case of vultures and adjutant birds. In Agra, if there is a wind, ascending currents are reflected upwards from the walls of high buildings such as the Taj and the Fort. The lighter birds, namely, cheels and scavengers, do take advantage of these currents especially when the air is not soarable. But this is not the case with the heavier birds. Vultures and adjutants, if they show any skill in the matter, do so, not by finding, but by avoiding such currents. On one occasion I saw some vultures apparently circling in the ascending current over the Fort. I at once went in my motor to investigate, and found that the vultures were not over the Fort but were circling a few hundred yards beyond it. They had merely appeared to me to be over the Fort because my point of observation, the Fort, and the vultures, were in one straight line, which line made a right angle to the wind direction. Vultures may be seen circling everywhere over the city of Agra with the single exception that they avoid the ascending current reflected upwards from the fort walls. It would be a very difficult proposition to defend that vultures, that avoid with skill ascending currents known to exist, have skill in finding other ascending currents that are not known to exist.

The second possibility is that soaring birds take advantage of those ascending currents that I have described as "heat eddies." These ascending currents are of small size, and so far as the evidence goes, uniformly distributed. In these two respects heat eddies fulfil a necessary character of the physical basis of soarability, as the regularity of soaring flight is explicable if due to minute and uniformly distributed rising currents. I have shown that the morning development of soarability frequently coincides in time with the development of heat eddies. But we have been brought to the conclusion that this correspondence is due to the fact that both soarability and heat eddies are due to the same cause, namely, sun energy. That there is no direct causal relation between the two phenomena is proved by the following facts. Under certain conditions air may be completely unsoarable in the presence of heat eddies. Secondly, air may be soarable in their apparent absence. This has been observed not only in Agra but also in Naini Tal, where the presence of the slightest eddy movement in the air, had such existed, would have been revealed by the movement of the cloud masses. Therefore it is impossible to see how heat eddies can be the cause of soarability. It is highly improbable, and in a sense inconceivable, that there should be a second set of ascending currents, also of small size, and also uniformly distributed, that could subserve soaring flight.

We have seen that the relation of the centre of area of the wing to the centre of gravity in slow flex-gliding could be explained by ascending currents. But the same line of argument that leads to this conclusion also leads to the conclusion that the relation of the area to the centre of gravity cannot be explained by ascending currents in the case of fast flex-gliding.

The disposition of the wings of the bird when in an ascending current of moderate strength has been described, and has been shown to be different from the disposition assumed in circling and fast flex-gliding. On one occasion in a stormy wind I saw a cheel travelling horizontally for a few seconds with wings dihedrally down and with the tail furled and elevated. This is the disposition usually employed for gliding downwards at speed. Its use in this case may be explained by supposing that the bird was, for a few seconds, in a strong ascending current. Thus, observation of the disposition of the wings may, to a certain extent, give information as to whether or not the bird is subjected to an ascending current, and, in fact, such observations show that in ordinary soaring flight ascending currents, capable of affecting the bird, are absent.

Therefore there is no evidence whatever in favour of the view that the energy of soaring flight is derived from the kinetic energy of air in movement independently of the bird's wing. There is a good deal of evidence against this view.

Thus we are led to the conclusion that the energy used in soaring flight is stored up in the air in potential form. There must be some substance or structure in which this energy is stored. For this unknown physical basis of soarability I propose the name "ergaer." The name no more implies that the matter is understood than does the name "protoplasm" imply that we know the nature of life. In one case, as in the other, the name stands for an unknown thing which is a subject of discussion.

In an earlier chapter I permitted myself to make a sarcastic remark about an observer who said that soaring flight was due to "levitation." Perhaps a critic may make a sarcastic remark about another observer who says that soaring flight is due to "ergaer." But the difference between the two cases is this. The author of the idea of levitation regarded it as a final explanation of soarability and implied that further research is unnecessary. On the other hand, ergaer is presented as the subject of a research that has only just begun, a research too in which I have little hope of being able to play a part. Mere scraps of time, such as I have been able to devote to cataloguing the bare facts relating to soarability, are quite insufficient for carrying out the serious experimental research that is now urgently required if the matter is to be carried further. The resources of a physical laboratory are needed to throw a light on the hundred questions that demand an answer. Is ergaer an unstable gaseous compound, or some allotropic modification of one of the gases of the air? Or does it consist of clusters of molecules that can fly apart, liberating energy, when disturbed by the passage of a vulture's wing? Or are we dealing with minute eddies whose circular motion is changed to tangential motion by the disturbance in question? What are the exact conditions under which ergaer is formed or decomposed? Perhaps the answers to such questions may lead to results of practical importance. If so, after the observer and experimenter, it will be the turn of the engineer, who, perhaps, cannot experiment, but who can design and construct. And, lastly, the general public, who can neither observe nor experiment, nor design, will reap the benefit.

Thus we have reached the conclusion that the air under the wing of a soaring bird is undergoing a change of the nature of a sort of continuous explosion. This view is perhaps unexpected and surprising. But the question arises whether it is the only case in which a change of potential to kinetic energy takes place in the air. The appearance of a gust of wind is only less surprising than soaring flight because it is so familiar. On a calm morning, before heat eddies have developed, a gust of wind arises and dies away in the absence of any apparent cause or reason. Evidence is completely lacking that energy from any external source is the cause of the

phenomenon. Now that we know that energy can be stored in the air in potential form, it becomes probable that this stored energy is the cause of wind, or of some kinds of wind, besides of soarability. It seems hardly likely that air possesses two distinct mechanisms by which energy can thus be stored. Hence we may expect that evidence will be obtained that ergaer is the cause of some kinds of wind besides being the source of soarability. On general grounds we may expect that evidence bearing on this possibility would be hard to find in settled weather or in constant winds. But in the presence of gusts, and at the time of a change of season, we may hope to observe phenomena indicating some connection between soarability and wind. It will be seen in the sequel that the study of "disturbed weather soarability" and "storm soarability" does lead to some evidence in favour of this suggestion.

But the knowledge of soarability now obtained puts us in a position to appreciate some evidence I have to put forward bearing on the functions of the wing-tips, to which subject the next few chapters will be devoted.

CHAPTER XL.—The Angle of Incidence.

In the case of aeroplanes the wings have a fixed position in relation to the direction of pull of the engines. The angle of incidence is therefore definitely settled before the aviator leaves the ground. So far as the direction of movement of the aeroplane is due to the pull of the engine there is no change in the angle of incidence during flight.

The bird, lacking a motor, has no such definite and simple method of maintaining its angle of incidence.

Let us consider an imaginary case of a bird suspended by a string attached to it at its centre of gravity. Let us further suppose that the air surrounding the bird is destitute of movement. We will suppose that the wings are stretched out horizontally in the position they assume during ordinary gliding flight. Under such conditions the bird has no difficulty in rotating its wings round their long axis. The axis round which the wing rotates is very near its anterior margin. Supposing now the air surrounding the bird is set in motion and that the bird faces the air current, and let us suppose further that the wings lie in the horizontal plane so that there is no angle of incidence. If the bird now commences to rotate the wings upwards, that is to say, in such a direction that their posterior margins go downwards, then the air begins to press on the underside of the wing. The centre of this pressure is somewhere between the centre of area and the anterior margin. The position of this centre of pressure will vary under different known conditions. In slow flight, at all events, this centre of pressure must be situated behind, that is to say, posteriorly to the axis round which the wing rotates. From this it follows that, if no other factor intervenes, rotation of the wings in one direction may result in rotation of the body in the opposite direction. We have, therefore, to consider by what means a bird can maintain or change the angle of incidence of its wings during flight without subjecting its body to rotation round the transverse axis.

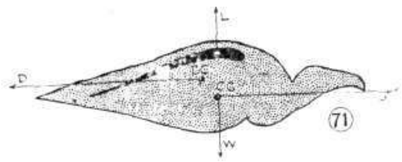
Let us first consider the case of a bird at the commencement of a period of gliding when in flap-gliding flight in unsoarable air. Let us imagine that the bird is travelling horizontally. The bird is being acted on by the four chief forces. Of these the "lift" and the "weight" act at points, one vertically above the other, as elsewhere explained. The other two forces are the "pull" and the "drag." The "pull" consists of the momentum of the bird. This acts in a horizontal direction at the centre of gravity (see Fig. 68). The "drag" consists of the resistance of the body of the bird to passage through the air, plus the resistance due to the action of the air on the wings. The "drag" must therefore act in a horizontal direction backwards. It probably acts at a point slightly above the level of the centre of gravity. But its exact position, that is to say, the position of the "drag centre," is unknown. In slow-flapping flight the head end of the bird rises during the down stroke and falls during the up stroke. The transverse axis round which this rotation occurs probably passes through the "drag centre." In flapping-flight there is an increase of transverse axis and dorso-ventral axis stability. These facts suggest that the "drag centre" is situated posteriorly to the centre of gravity. Just as the "lift" and the "weight" act at two points some distance apart, one above the other, so, that is to say, it is probable that the "pull" and the "drag" act at different points, one behind the other, thus conferring a small measure of natural stability.

Since the "drag" consists not only of the resistance due to the action of the air on the body, but also of resistance due to the action of air on the wings, there can be little doubt, that, under the conditions described, it is situated on a slighty higher level than the centre of gravity. If this is the case there must be a couple between the "pull" and the "drag" that tends to rotate the bird upwards round its transverse axis, in other words that tends to maintain the angle of incidence.

When a bird is gliding in unsoarable air with loss of height it is probable that no other factor intervenes to maintain the angle of incidence.

But suppose the bird was to glide into a patch of soarable air and was to continue gliding with wings at full camber. Then, under these conditions, the "pull" would no longer act at the centre of gravity. It would no longer consist of the momentum. It would consist of the tractive effect of soarable air on the cambered wing. That is to say the "pull" would act on a level with the wings (Fig. 72). Hence the above described means of maintaining the angle of incidence would no longer be operative. Apart from the wing tips, the wings act, not as a resistance, but as a source of tractive effort. Hence the "drag" consists, not of the action of the air on the wings plus the resistance of the body of the bird to passage through the air as before. It consists of the last mentioned factor plus such resistance as may be derived from the wing tips.

The question we have to solve is how the angle of incidence is maintained in soarable air with the wings at full camber. Facts in my possession tend to show that this function belongs to the phalangeal quills. If a bird is gaining height, with wings at full camber, the wing tips are rotated upwards. The air pressure on the underside of the phalangeal quills must tend to lift up the anterior margin of the wing. (See Figs. 62 and 63.) A proof of the truth of this assertion will be found in the fact that the degree of upward rotation of the wing-tip is proportional to the amount of energy being taken from the air. Before describing the facts on which this assertion is based, it will be convenient to consider the position of the wing-tips in flex-gliding.



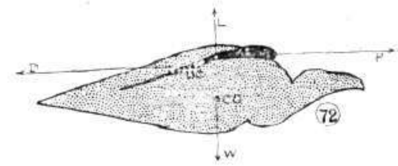


Fig. 71.—Vulture flap-gliding in unsoarable air at commencement of a glide. P pull, D drag, L lift, W weight, CG centre of gravity, DC drag centre.

Fig. 72.—Vulture gliding in soarable air with wings at full camber. P pull, D drag, L lift, W weight, CG centre of gravity, DC drag centre.

In flex-gliding the wing-tips are retired by flexing at the carpal joint. When viewed from below, the phalangeal quills are seen to be directed backwards and outwards. But when the bird is viewed from the side, the phalangeal quills appear to be bent upwards, as shown diagramatically in Fig. 74. This is not always easy to see. If the bird is seen from behind, the tips, owing to their position, appear foreshortened, and the full extent of their upward bend is not apparent. When the bird is gliding past, giving a broadside on view, and especially after it has passed the exact broadside on position, the phalangeal quills of the near wing can be seen to be strongly turned up, but only a slight turning up of the far wing-tip is visible. This again is obviously owing to foreshortening. I have often watched a flex-gliding bird while travelling in a straight line for long distances, probably as much as a mile or more, and have been able to see the quill feathers of the near wing bent up and destitute of any sign of movement. I recently observed a black vulture fast flex-gliding at an unusually short distance. It passed me broad side on. As it was coming up to this position, I distinctly saw the curvature of each individual feather, as indicated in Fig. 74. The fact that the quills were curved and not straight, proves definitely that their position was due to air pressure and not due to rotation of the wing. That a considerable force is necessary in order to produce the curvature observed, is indicated by the following measurements:—

An adjutant of 9 ft. 6 ins. span was placed lying on its back on a table. It was found that the following weights were necessary in order to make the quill feathers lie flat.

1st primary quill...	20 grammes	5th primary quill...	90 grammes
2nd ,, ...	30 ,,	6th ,, ...	70 ,,
3rd ,, ...	60 ,,	7th ,, ...	10 ,,
4th ,, ...	60 ,,	8th ,, ..	0 ,,

Obviously, in order to bend the quill feathers further, that is to say, beyond the flat position to the position observed in flex-gliding, much greater weights would be required. In the case of the quill feathers of the dried wing of a vulture, I found that weights approximating 150 grammes were necessary for the purpose. The weights were placed two or three inches from the end of each feather.

These observations indicate a method by which the force exerted by ergaer might be measured. In the first place it would be

necessary to get accurate information as to the actual amount of deflection of the phalangeal quills. This might possibly be done by photographs taken with a telephoto lens. Then it would be necessary to hold the quills in an air-current and find what current-speed was necessary to cause a deflection identical with that observed in flex-gliding. But, even in the absence of such accurate data, the facts now brought forward indicate that the force exerted by ergaer is greater than could be yielded by "heat eddies" or by any ascending currents whose existence could reasonably be assumed.

I have already stated that when circling in fully soarable air, with effort to gain weight, the wings are advanced and placed in a dihedrally-up position. Obviously, this disposition must place the wing-tips in the most favourable position for influencing the angle of incidence (Fig. 63). If the bird is circling without effort to gain height, the wings are not advanced, but straight. Also the dihedrally-up angle is reduced. With this disposition the wing-tips are in a less favourable position for affecting the angle of incidence (Fig. 62). In both these cases the wing-tips are kept rotated upwards to their fullest extent, and the phalangeal quills are lifted by the pressure of the air to different degrees, as shown in a previous chapter, in Fig. 23. Supposing the bird circles with the wing tips rotated upwards to lesser amounts, then less energy is taken from the air, as illustrated by the following observations :—

August 29th, 1911, at 4.25.—A vulture seen descending slowly. Its wing tips were only slightly rotated upwards. The first phalangeal quill could be seen to be slightly turned up. It remained with the wing tips in this position during the whole of its descent. It took nearly ten minutes to descend through 300 metres. It was descending in circles and was in the direction of the Taj.

4.30.—Another vulture descending. Its wing tips were flat, but not retired (indicating that the angle of incidence was not so much diminished as in metacarpal descent). It took two or three minutes to descend through 300 metres.

Owing to the natural curvature of the quill feathers, air must be exerting some pressure on their under sides for them to assume the flat position. As elsewhere described, in metacarpal descent, besides being flat, the wing tips are retired, thus still further diminishing their action in maintaining the angle of incidence.

In the above cases the same disposition of the wing tips was assumed for each wing. In the following two observations I saw the effect produced by rotation of a single wing tip :—

19th August, 1911.—At Jharna Nullah. 6.0 p.m.—Wind moving small branches. Some eagles seen flap-gliding. Twice a wing tip rotation was seen to be followed by a small decrease of the angle of incidence of the wing.

In each of these cases, a steering effect was produced. The wing tip rotation was small, not sufficient to produce a typical dip movement. Neither was there any appearance of a wing depression. The following is a similar observation :—

October 8th, 1911.—At Jharna Nullah. 10.0.—Wind south moving leaves. 10.38.—A vulture made a slight wing tip rotation. This was seen to be followed by a decrease of the angle of incidence of the affected wing.

I was particularly fortunate in being able to make this last observation. I had never expected to be able to see this movement in a vulture. I was seated in a slight depression in the ground, within about ten yards of one or two hundred vultures that were busily eating carrion. Many vultures were descending or gliding near me at low levels.

We are now in a position to understand the cause of the steering effect produced by a dip movement. The evidence now brought forward indicates that the steering action is due to the inside wing being given an angle of incidence inappropriate to its camber. Some facts to be described in the next chapter will be found to be in harmony with this conclusion.

My observations have therefore led to the belief that the wing-tips have two functions. First, steering in the horizontal plane. This is produced by rotation downwards of one wing-tip, with consequent loss of speed of the wing, whose tip is rotated. Secondly, maintenance of the angle of incidence, both in soarable air and when flap-gliding, with effort to maintain or gain height.

Presumably, the fact that the primary quills are separate, aids the lifting effect, while presenting less resistance to forward movement through the air than would be the case if these feathers overlapped.

A further and welcome proof of the correctness of the above views of the functions of the wing-tips would be obtained if they led to an explanation of the movements of the deformed vulture, described in Chapter XXV. Though it is possible to make a vague guess as to the reason of the disposition of its efficient wing-tip there described in the light of the present knowledge, it appears to me that, before a final conclusion can be arrived at, we must know more about the play of forces in circling, and also obtain further information as to the exact nature of the deformity. The vulture in question when seen in 1911 was found to have the same deformity as when first seen in 1910. *(To be continued.)*

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Flying at Night by Searchlight.

A CORRESPONDENT sends us the following interesting account of a night in America by Mr. George M. Dyott, a member and pilot of the Royal Aero Club :—

"The sensation of the week ending October 28th at the Nassau Aerodrome in New York was the ascent by night of two Englishmen, Mr. George Dyott, with Captain Hamilton as passenger, in a Deperdussin monoplane. With the aid of a powerful searchlight attached to the running gear of his aeroplane and connected by electric wires, Mr. Dyott flew all about the vicinity of the Nassau Aerodrome and landed without even straining a wire.

"The other machines had been in their hangars for some time, and all was a thick inky darkness when Mr. Dyott ended his remarkable flight. Captain Hamilton manipulated the searchlight and picked out a landing for Mr. Dyott near his hangar.

"The aeroplane presented a most remarkable appearance in the dark sky with the searchlight sending its rays in all directions. At times the light would be shut off, and except for the throbbing of the motor the location of the aeroplane could not be determined. As the monoplane came down from a height of 300 feet the searchlight was turned towards the ground, and the spectacle resembled a monster shooting star rushing earthward.

"Captain Hamilton, who has had much experience in aeronautics in England and France, declared the experiment to be a marked success, and that it would be but a short time before aeroplanes would be flying at night whenever occasion required.

"Mr. Dyott took his *brevet* at the Blériot School of Aviation at Hendon last summer, and afterwards spent several weeks in France at the Deperdussin School of Aviation; from there he went to the magnificent works of the Deperdussin Company, and watched the building of the two fine machines which he and Captain Hamilton took with them to America.

"Mr. Dyott and Captain Hamilton left New York on November 1st for Mexico City, where they have arranged to fly for a month."

Mr. G. M. Dyott and Capt. Patrick Hamilton of the Worcestershire Regiment, who have been flying so well in America after learning to fly in England.

A Study of Bird Flight

By Dr. E. H. Hankin, M.A. DSc.

Chapter XLI.—Changes of Camber of the Wing of Flying Foxes during Flight.

In the preceding chapter I pointed out that a particular angle of incidence is appropriate to a particular amount of camber. For instance, if the angle of incidence is diminished while the camber is maintained, then there is loss of speed, as seen both in metacarpal descent and in ordinary steering by dip movements. If, on the other hand, the angle of incidence is diminished, and, if at the same time, the camber is proportionately diminished, then there is increased speed, as seen in flex-gliding and in shoulder descent. I have now to describe facts that show that flying foxes make a similar use of changes of camber.

When describing the anatomy of the wing of flying foxes (Chapter XXXI), I made the following statement:—

"There is a muscle that can rotate downwards or turn downwards the middle third of the anterior margin of the wing. This is the part of the anterior margin that is supported by the first two digits, and that extends in front of the main bony framework. By the turning downwards of the front margin of the wing the camber may be increased."

As the thumb supports this anterior part of the wing membrane (see Fig. 75) and extends beyond it, it is obvious that observations of the position of the thumb during flight might give a clue to changes of camber that in themselves are invisible. Such observations are very difficult to make, both owing to the speed of the bat and owing to the dimness of the light. The presence of the full moon is no advantage, as it seems to make the bats start later than usual. Causing them to fly by throwing stones during the day results in hurried flight of no use for my purpose. It rarely

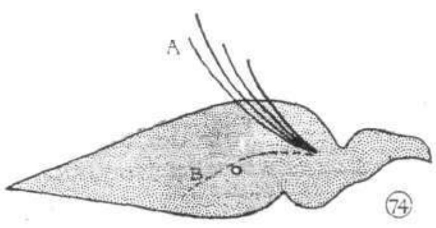

Fig. 74.—Diagram showing position of phalangeal quills in fast flex-gliding. A shows the actual observed position of the quills. At B is shown the position that these quills would take up in the absence of air pressure.

happens that a flying fox, when gliding, remains near enough to observe for so long as a second. At the time that the majority of the flying foxes start on their evening flight it is too dark to see any traces of the thumbs. But some minutes before their time of departure a few individuals flap or glide from one tree to another. With practice and by careful observation, glimpses may sometimes be had of the position of the thumb in these cases. But these observations are so difficult that I doubt whether increased acquaintance on my part with flying foxes would add appreciably to the knowledge of their flight that I have already gained.

My earlier observations are as follows:—

September 22nd, 1910.—A flying fox flapping downwards at a small angle with the horizon seemed to have the thumbs turned downwards.

September 23rd, 1910.—When gliding downwards with wings dihedrally down, or arched, or both, the thumbs appear to be pointing downwards. When flying upwards the thumbs appear to stick out straight in front (*i.e.* camber at minimum or abolished). In horizontal flapping flight they appear to stick out straight in front with very slight inclination downwards.

September 24th, 1910.—In steering (in the horizontal plane), I formed the impression that, besides arching the inside wing, the thumb of this wing is also turned down.

Having no clear idea of the meaning of these facts, I made no mention of them when writing the earlier chapter dealing with flying foxes. Some recent observations throw further light on the matter.

September 24th, 1911.—A flying fox seen to increase arching and flexing of wings for rapid descent. The result was that besides gliding ahead, it was noticeably dropping through the air. This was carpal and elbow flexing. No flexing occurred at the shoulder joint, because there was no rotation round the transverse axis. It was equivalent of carpal descent.

Another flying fox seen gliding downwards with wings strongly flexed and arched. Its thumbs were pointing downwards. This was shortly afterwards seen in another case. A flying fox gliding with wings arched seen to steer by increase of arching of inside wing. Thumbs were again seen pointing downwards in carpal descent.

September 25th, 1911.—In several cases, I saw that in flapping flight the thumbs are directed horizontally forward. In these cases the animal was flying either horizontally or at a slight upward angle with the horizon.

When gliding with wings slightly arched, and with no appreciable loss of height, the thumbs are directed forward with a very slight downward inclination. This was again seen.

When gliding with small loss of height, the thumbs are directed downwards and forwards.

That is to say, when flying foxes are gliding horizontally the camber is at a minimum. When arched gliding with slight loss of

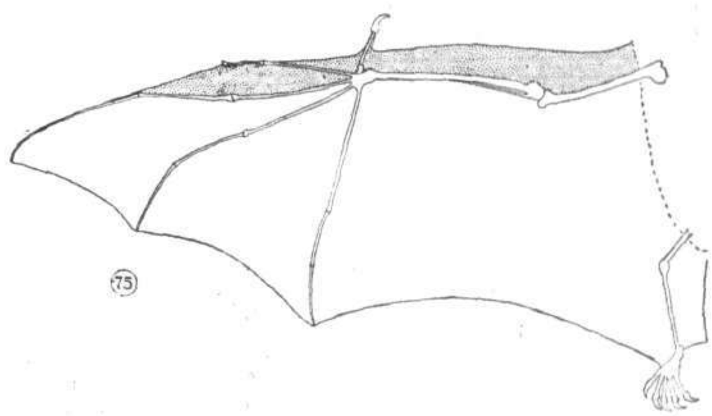

Fig. 75.—Outline of wing of flying fox. The shaded area shows the part of the wing membrane that is turned down to produce camber. The turning down affects chiefly the part of the wing membrane included between Digits I and III.

height, there is medium camber. When gliding downwards steeply—certainly without increase of speed, and probably with loss of speed—the camber is at a maximum. Previous observations have shown that in this latter case the angle of incidence is diminished. Hence it appears probable that we again have a case of checking speed by giving the wings a degree of camber unsuited to the angle of incidence.

Further observations show that flying foxes make another use of change of camber:—

September 29th, 1911.—A flying fox gliding upwards had thumbs horizontal.

September 30th, 1911.—A flying fox gliding downwards had thumbs pointing downwards. A flying fox gliding horizontally had thumbs very slightly inclined downwards. When gliding just before perching they pointed strongly downwards. Another also showed thumbs directed downwards just before perching. Another gliding horizontally showed thumbs directed forward nearly horizontally. A flying fox gliding showed thumbs pointed downwards just before poise flapping before perching. A flying fox making half flaps had thumbs directed horizontally forward.

October 2nd, 1911.—A flying fox gliding horizontally seen to turn thumbs downwards to check speed. A flying fox gliding had thumbs directed slightly downwards. Then, to check speed just before perching, the thumbs were turned strongly downwards.

Then it began poise flapping and perched. This again seen three times. Thumbs seen turned slightly downwards for flapping at low speed. Flexing and increased arched of inside wing seen for steering in flapping flight.

October 4th, 1911.—Thumbs seen stretched out horizontally in horizontal flapping flight. This seen again repeatedly. A flying fox gliding downwards with wings arched had thumbs turned down. A flying fox gliding seen to increase arching of inside wing for steering. A flying fox in flapping flight seen to steer by increasing the arching during the down stroke of the inside wing.

October 5th, 1911.—A flying fox seen to direct thumbs downwards in gliding just before perching. A flying fox in flapping flight seen to direct thumbs downwards just before perching.

These observations prove that in gliding before perching there is an increase of camber. But at this time the wings are advanced. This advancing produces rotation round the tranverse axis, and the angle of incidence is consequently increased. Therefore, unless the movement is purposeless, it appears probable that in this case increased camber prevents dropping through the air or has some other beneficial action when speed is checked by the large increase of the angles of incident.

Parenthetically, I may state that during this period before perching (whether flapping or gliding) the hind legs come apart. No doubt this is due to the effect of the pull on the wing menbrane caused by advancing the wings. In ordinary flight the hind legs lie parallel and close together.

From the above observations, it appears probable that arching to a large extent, is necessarily associated with turning down of the thumbs. In the human hand the thumb and first finger can be rotated downwards to a slight extent (supposing the hand is held palm downwards) without the movement of the middle finger. But rotation downwards of the thumb and first finger to a large extent causes a downward movement of the middle finger. The facts described suggest that the same relations hold in the case of the digits of the flying fox.

The use of change of camber seems to be the same whether the animal is flapping or gliding. I have previously shown that steering in flapping flight is caused by increase of arching of the inside wing during the down stroke. It is an interesting possibility that this increase of arching is a sign of momentary increase of camber. If this increase of camber exists it must coincide with a decrease of the angle of incidence, for the increase of arching is accompanied by a small amount of flexing, and, owing to the structure of the bat's wing, flexing at any joint must slacken the membrane and so diminish the angle of incidence. It will be at once objected to this view that we have no right to speak of an angle of incidence during flapping flight, but the force of this objection will be lessened by the following consideration :—

When an adjutant bird is observed in a gliding period of flap-gliding flight, in end-on view, the wing-tip feathers are seen to be spread out like the wings of a fan, as illustrated in Fig. 23. That is to say, the wing-tip is rotated upwards in order to maintain the angle of incidence. This is always the case when there is effort to maintain or gain height. When gliding with loss of height, with or without arching of the wings, the wing-tip is rotated upwards to a lesser degree, so that the phalangeal quills lie nearly or quite in the same plane. Supposing the bird commences flapping, the wing-tip feathers remain spread out as before like the ribs of a fan. I have long suspected that they retain this disposition during the whole of the up stroke and during the whole of the down stroke. I have recently been able to see definitely that this is the case both in adjutants and in vultures when in ordinary flapping flight with effort to gain or maintain height. In a recent observation the degree of spreading out the wing-tip feathers appeared to be slightly less in flapping than in gliding with maintenance of height. My observations relate to birds observed flapping at low levels. It does not necessarily follow that the tip feathers are turned up when flapping at high levels when there is more effort to gain speed than height. The amount of retirement of the wing tips during flapping appears to be different under different conditions, but what these conditions are I have not yet been able to determine.

This turning up of the wing-tip feathers during flapping must be due to air pressure. At first sight it is difficult to understand how such pressure can cause this turning up during the up stroke. But it must be obvious than in gliding with effort to maintain height, the spreading out of the feathers is not due to air pressure from below, but to the air pressure due to there being speed ahead. That is to say it is due to air pressure from in front. When flapping, this pressure from in front must remain during the up stroke, and consequently the tip feathers can remain spread apart if the wing tip is kept rotated upwards. But if the pressure from in front acts thus in supporting the tip feathers, it must also act on the under surface of the wing generally. That is to say, during the up stroke the bird s still getting lift from the air in virtue of its speed ahead. Already in Chapter XXX, I brought forward grounds for believing that flapping flight consists of gliding with flapping superadded. The considerations now brought forward support this conclusion.

But it does not follow that in all species of birds, or always in adjutants and vultures, that the wing-tip is kept rotated upwards during flapping flight. Two species of wading birds are known to me whose rate of beat is unusually slow, and in which flapping occurs with the wings arched throughout the stroke and with the wing tips flat. Also in these birds the up stroke terminates unusually early. That is to say, when the up stroke ends the wings have scarcely risen to the level of the back of the bird. These last two facts strongly suggest that, in these birds, flapping occurs with a smaller angle of incidence (so far as gliding is concerned) than is the case in the flapping flight of vultures and adjutants. But it is clear that in this point, as in many others, my observations only touch the fringe of knowledge that is readily accessible. The facts now brought forward suggest an interesting line of research, namely, as to whether there is some relation between loading, rate of beat, and the position of the wing-tips during flapping flight. Such a research might throw light on the fact that so many different species of birds have almost the same rate of beat.

Although my remarks on camber deal, not with new principles, but with new applications of principles already known, it is probable that further knowledge of this subject is attainable, and that it might be obtained in other ways than by observation of birds or bats.

For instance, it is possible that information might be obtained by experiments with a glider. For this purpose a biplane glider might be constructed having a means of adjusting independently the camber of the wings during flight. If, during a glide, the camber of the two wings of one side was increased, one would expect a steering effect towards that side to occur. Experiment would be necessary to find whether a means of altering the angle of incidence would be required *in addition in order to produce this effect.* One would expect that steeringin the horizontal plane, thus produced, to cause less canting ; that is to say, less drop of the wing whose speed is checked than would be caused by certain other methods of steering. Further, if the camber of both the wings of one of the planes was increased during a glide, one would expect rotation round the transverse axis to be produced. That is to say, if the camber of the wings of the upper plane was increased, one would expect the biplane to tend to glide upwards. If the camber of the wings of the lower plane was increased one would expect the glider to glide downwards. That is to say, one would expect these changes of camber to furnish a means of maintaining longitudinal stability.

Before leaving the subject of flying foxes, I will make a further quotation from my diary, omitted from previous extracts as it had no bearing on the preceding discussion.

September 24th, 1911.—Sun already set. A small thunderstorm to east. A puff of dusty wind moving branches. Flying foxes gliding to leeward of small trees broadside on to wind occasionally showed momentary flexing, as if as an "emergency adjustment" for dealing with wind irregularities.

An "emergency adjustment" can also be seen in the flight of vultures and other birds. If a vulture is startled by suddenly discovering the approach of another bird, or by a rifle bullet whizzing past it, it suddenly flexes its wings and lowers it legs. A relaxation of the secondary feathers may also be seen. That is to say, the vulture changes its flight to "carpal descent." By lowering the position of the centre of gravity, and by decreasing the supporting area of the wings, it thus turns itself into a sort of parachute. But, as already explained, the indisposition of the secondary quills in this form of descent is such as to permit of speed ahead rather than the irregular swaying of an actual parachute. As soon as the danger is past the bird expands its wings and resumes its flight. Twice, or perhaps three times, I have, as I think, seen this adjustment used for dealing with an atmospheric irregularity. Presumably if the bird was canted and the upper wing was struck by a gust of wind, the flexing would affect the upper wing first in order to hasten the return to a level keel.

Conclusion.

I have decided to interrupt at this point the publication of my papers on the flight of birds. An interlude is now desirable for two reasons. Firstly, time is required for me to find out in which directions my imperfect observations need extending and amplifying. Secondly, the greater number of the facts that I have discovered during the past year relate to subjects that I doubt whether I am yet competent to discuss.

The knowledge already gained is worth attention in that it appears to offer a means of research on certain obscure meteorological problems. There is reason for hoping that systematic study of soaring flight will lead to knowledge, perhaps not otherwise attainable, of the secret of the air, its store of energy, and its ceaseless change.